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# Comparative Diets of Paiute Sculpin, Speckled Dace, and Subyearling Steelhead Trout in Tributaries of the Clearwater River, Idaho

## Abstract

The food habits of Paiute sculpin (*Cottus beldingi*), speckled dace (*Rhinichthys osculus*), and subyearling steelhead trout (*Salmo gairdneri*) were examined during summer and early fall when they coexist in riffles. A total of 196 Paiute sculpin, 186 speckled dace, and 194 subyearling steelhead trout from six tributaries of the Clearwater River, in North Central Idaho, were used for analysis. Paiute sculpin fed exclusively on autochthonous material whereas steelhead utilized both autochthonous (42-82 percent, $\bar{x}$=65 percent) and allochthonous (10-58 percent, $\bar{x}$=34 percent) foods. Detritus (46-77 percent, $\bar{x}$=66 percent) was the major food in the diet of the speckled dace. Overlap in diet of speckled dace with both Paiute sculpin (0.102-0.336, $\bar{x}$=0.167) and subyearling steelhead (0.062-0.250, $\bar{x}$=0.161) was very low. Diet overlap between Paiute sculpin and subyearling steelhead was moderate (0.489-0.553) in five of the streams and high (0.869) in one. The data suggest that during diurnal periods there is definite delineation in the foods eaten by these three species when they coxist in riffle habitats during the summer and fall.

## Introduction

Competition for food resources may be facilitated when different fish species occupy the same microhabitat. In these instances, competitive interactions may be reduced if sympatric fishes 1) feed on different types or sizes of prey, 2) feed at different locations in the water column (i.e., bottom, mid-water, surface), or 3) feed at different times of the day. Of these three categories, feeding at different times of the day may reduce interspecific interactions between species but may not substantially diminish competition since a similar diet may still deplete a shared food resource.

In tributaries of the Clearwater River, Idaho, the dominant fish assemblage in the streams through the summer and early fall consists of Paiute sculpin (*Cottus beldingi*), speckled dace (*Rhinichthys osculus*), and subyearling steelhead trout (*Salmo gairdneri*) (Kucera *et al.* 1983). During this period these three species predominantly occupy riffle areas. The utilization of riffle habitat by Paiute sculpin, speckled dace, and subyearling steelhead trout has led to a number of investigations examining interactions between these species with other coexisting riffle inhabitants (Dietsch 1959, Hannuksela 1973, Li and Moyle 1976, Baltz *et al.* 1982, Finger 1982). The focus of this study was to utilize both the information gained in evaluating similarity in diets between these species in Clearwater River tributaries plus the available data in the literature to assess the potential for competition when these species coexist in riffles.

## Methods and Materials

Fishes were collected from 3 August to 6 October 1982 in six tributaries of the Clear-

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water River in North Central Idaho. The six streams, Bedrock Creek, Big Canyon Creek, Cottonwood Creek, Jacks Creek, Lapwai Creek, and Mission Creek, discharge into the Clearwater River within the Nez Perce Indian Reservation (Fig. 1). A general description of the collection site of each stream is presented in Table 1.

Fishes were preserved in 10 percent formalin after being stunned with an electroshocker. Diet composition was determined on a dry weight basis from estimates de-

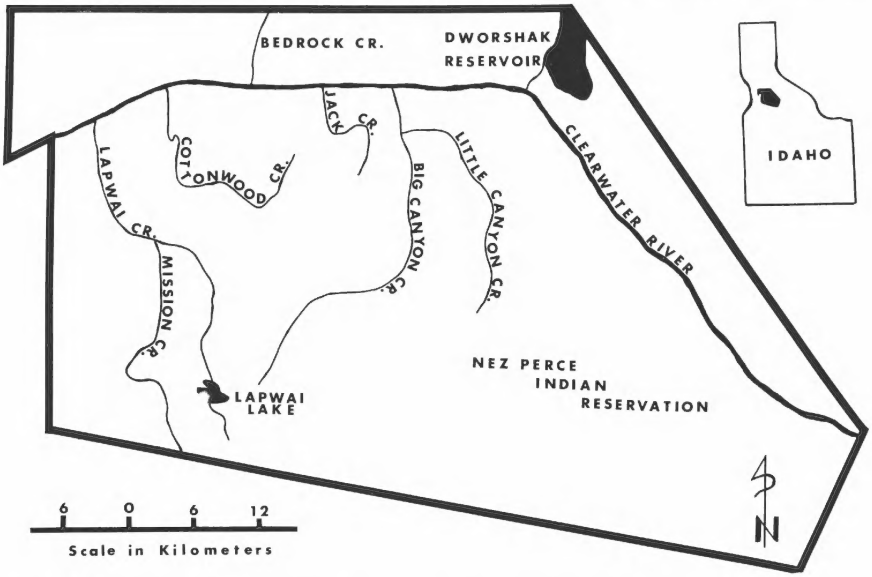


Figure 1. Location of the study streams within the Nez Perce Indian Reservation, Idaho.

rived for individual prey taxa. Whenever possible, aquatic invertebrates were identified to family, terrestrial invertebrates to order, and fish remains to species.

Diet overlap between Paiute sculpin, speckled dace, and subyearling steelhead trout in each stream was calculated using the equation of Horn (1966):

$$C\lambda = 2 \frac{\sum_{i=1}^{s} X_i \cdot Y_i}{\sum_{i=1}^{s} X_i^2 + \sum_{i=1}^{s} Y_i^2}$$

where $C\lambda$ = overlap value
$s$ = food categories
$X_i$ = proportion of the total diet of fish species X contributed by food category i
$Y_i$ = proportion of the total diet of fish species Y contributed by food category i

When employing this equation diet overlap values ($C\lambda$) can range from 0 (no overlap) to 1 (complete overlap).

TABLE 1. Stream length (km), collection location (km from stream mouth), average stream width (m), maximum temperature (C°), and water velocity (cm/s) for study streams and stations. Estimates at each collection location for stream width, maximum temperaure and velociy represent late summer conditions.

| Stream | Length | Location | Width | Temperature | Velocity |
|---|---|---|---|---|---|
| Bedrock Creek | 15 | 2 | 3.8 | >20° | 25.9 |
| Big Canyon Creek | 48 | 14 | 9.1 | 26° | 34.6 |
| Cottonwood Creek | 26 | 7 | 3.6 | 23° | 17.8 |
| Jack's Creek | 13 | 8 | 2.3 | 23° | 14.7 |
| Lapwai Creek | 45 | 25 | 5.5 | 27° | 33.9 |
| Mission Creek | 34 | 22 | 3.5 | 26° | 19.5 |

TABLE 2. Number of fish examined, mean length and size range (TL, mm), and date of collection, from six tributaries of the Clearwater River, Idaho.

| Stream | Date | Species | Number | Mean | Range |
|---|---|---|---|---|---|
| Bedrock Creek | 08/03/82 | Paiute Sculpin | 12 | 50.7 | 44-63 |
| | | Speckled Dace | 40 | 68.3 | 58-78 |
| | | Steelhead 0+ | 20 | 70.6 | 59-83 |
| Lapwai Creek | 08/03/82 | Paiute Sculpin | 55 | 65.9 | 53-97 |
| | | Speckled Dace | 60 | 68.0 | 54-87 |
| | | Steelhead 0+ | 83 | 63.0 | 53-85 |
| Jack's Creek | 09/23/82 | Paiute Sculpin | 27 | 64.0 | 46-98 |
| | | Speckled Dace | 10 | 72.0 | 63-79 |
| | | Steelhead 0+ | 20 | 71.8 | 60-92 |
| Mission Creek | 09/28/82 | Paiute Sculpin | 43 | 66.1 | 54-89 |
| | | Speckled Dace | 16 | 77.7 | 45-94 |
| | | Steelhead 0+ | 21 | 79.3 | 71-92 |
| Big Canyon Creek | 10/01/82 | Paiute Sculpin | 30 | 73.1 | 59-70 |
| | | Speckled Dace | 40 | 73.4 | 62-83 |
| | | Steelhead 0+ | 24 | 84.2 | 66-100 |
| Cottonwood Creek | 10/06/82 | Paiute Sculpin | 29 | 65.0 | 46-102 |
| | | Speckled Dace | 20 | 57.4 | 40-86 |
| | | Steelhead 0+ | 26 | 90.5 | 76-102 |

## Results

The diets of 196 Paiute sculpin, 186 speckled dace, and 194 subyearling steelhead trout from six Clearwater River tributaries were used for analysis (Table 2). The three species were collected in sufficient numbers to quantify thair diets in each of the six streams. Sample sizes from individual streams consisted of a low of 57 fish from Jacks Creek to a high of 198 fish from Lapwai Creek (Table 2).

Paiute sculpin fed exclusively on autochthonous material. Hydropsychids (15.0-40.9 percent, $\bar{x} = 27.2$ percent), chironomids (17.7-28.5 percent, $\bar{x} = 23.7$ percent), and baetids (4.4-25.1 percent, $\bar{x} = 14.5$ percent) were the major prey consumed and were the only taxa that were represented in the diet of Paiute sculpin in each of the six streams (Table 3). Additional benthic taxa which were important in the diet of Paiute sculpin were perlodids and elmids (four streams), tipulids (three streams), perlids (two streams), and sialids (one stream). Fishes were only found in the diet of Paiute sculpin in one stream. In Big Canyon Creek fishes composed 41.4 percent of the diet of Paiute sculpin. The species is apparently cannabilistic since approximately 80 percent of the fish remains in the diet (one-third of the total diet of Paiute sculpin in Big Canyon Creek) was identified as Paiute sculpin.

The major component in the diet of speckled dace was detritus (46.1-77.0 percent, $\bar{x} = 65.5$ percent) (Table 4). Chironomid larvae (3.1-17.5 percent, $\bar{x} = 11.7$ percent)

TABLE 3. Percent dry weight dietary composition of Paiute sculpin in tributaries of the Clearwater River, Idaho. Only those prey taxon which composed at least 2 percent of the diet of Paiute sculpin in one or more of the streams are included.

| | Stream | | | | | |
|---|---|---|---|---|---|---|
| Aquatice taxon | Bedrock Creek | Lapwai Creek | Jacks Creek | Mission Creek | Big Canyon Creek | Cottonwood Creek |
| Plecoptera | | | | | | |
| Perlidae | —— | —— | 19.4 | 9.2 | —— | —— |
| Perlodidae | —— | 8.4 | 3.3 | 3.4 | —— | 15.9 |
| Ephemeroptera | | | | | | |
| Baetidae | 25.0 | 9.1 | 10.4 | 12.7 | 4.4 | 25.1 |
| Heptageniidae | 8.1 | 7.4 | —— | —— | —— | 2.9 |
| Unidentified | —— | —— | —— | 2.0 | 0.7 | —— |
| Trichoptera | | | | | | |
| Brachycentridae | —— | —— | —— | 2.5 | —— | —— |
| Glossosomatidae | —— | 0.3 | —— | 4.1 | —— | —— |
| Helicopsychidae | —— | —— | —— | —— | —— | 8.1 |
| Hydropsychidae | 40.9 | 32.6 | 27.6 | 23.0 | 23.8 | 15.0 |
| Limnephilidae | —— | 2.8 | —— | —— | —— | —— |
| Philopotamidae | 4.2 | —— | —— | 1.8 | —— | —— |
| Megaloptera | | | | | | |
| Sialidae | —— | —— | 9.0 | —— | —— | —— |
| Coloptera | | | | | | |
| Elmidae | —— | 3.6 | —— | 13.3 | 0.6 | 1.2 |
| Diptera | | | | | | |
| Chironomidae (L) | 21.8 | 17.7 | 28.3 | 19.0 | 26.9 | 28.5 |
| Simuliidae | —— | —— | 0.8 | 4.9 | —— | —— |
| Tipulidae | —— | 12.6 | 1.2 | 1.1 | —— | —— |
| Teleostei | | | | | | |
| C. beldingi | —— | —— | —— | —— | 33.1 | —— |
| Unidentified | —— | —— | —— | —— | 8.3 | —— |
| Miscellaneous | —— | 5.5 | —— | 3.0 | 2.2 | 3.3 |

L—Larvae

TABLE 4. Percent dry weight dietary composition of speckled dace in tributaries of the Clearwater River, Idaho. Only those prey taxon which composed at least 2 percent of the diet of speckled dace in one or more of the streams are included.

| | Stream | | | | | |
|---|---|---|---|---|---|---|
| | Bedrock Creek | Lapwai Creek | Jacks Creek | Mission Creek | Big Canyon Creek | Cottonwood Creek |
| **Aquatic Taxon** | | | | | | |
| Plecoptera | | | | | | |
| Perlodidae | —— | 5.2 | 6.9 | —— | —— | —— |
| Ephemeroptera | | | | | | |
| Baetidae | —— | 10.9 | 24.0 | 5.4 | 4.9 | 4.5 |
| Heptageniidae | 2.2 | 1.5 | —— | —— | —— | —— |
| Unidentified | 1.4 | —— | 5.5 | —— | —— | —— |
| Trichoptera | | | | | | |
| Hydropsychidae | 5.2 | 4.3 | —— | —— | 5.6 | 12.1 |
| Diptera | | | | | | |
| Chironomidae (L) | 14.2 | 9.4 | 17.5 | 10.7 | 15.1 | 3.1 |
| Tabanidae | —— | —— | —— | 11.3 | —— | —— |
| Tipulidae | —— | 7.1 | —— | 7.1 | —— | —— |
| Detritus | 77.0 | 57.5 | 46.1 | 65.5 | 73.9 | 72.7 |
| Miscellaneous | —— | 1.9 | —— | —— | 0.5 | —— |
| **Terrestrial Taxon** | | | | | | |
| Annelida | —— | —— | —— | —— | —— | 7.6 |
| Homoptera | —— | 2.2 | —— | —— | —— | —— |

L—Larvae

were the principal benthic prey consumed and were present in the diet of fish from all six streams. Baetid nymphs were the second ranking prey (0-24.0 percent, $\bar{x}=9.9$ percent), occurring in the diet of dace in five of the streams. Hydropsychids (four streams), perlodids and tipulids (two streams) and tabanids (one stream) also contributed substantially to the diet of speckled dace. Allochthonous foods were almost completely absent from the diet.

Subyearling steelhead trout fed heavily on allochthonous material. Terrestrial invertebrates comprised from 10.1-57.7 percent ($\bar{x}=34.2$ percent) of the diet of subyearling steelhead in the six streams (Table 5). The main terrestrial invertebrates consumed by steelhead were homopertans ($\bar{x}=8.7$ percent), coleopterans ($\bar{x}=6.5$ percent), arachnids ($\bar{x}=4.6$ percent), hemipterans ($\bar{x}=4.0$ percent), and hymenopterans ($\bar{x}=3.7$ percent). No single order of terrestrial invertebrates were represented in the diet of steelhead in each of the six streams. Chironomids (14.1-19.7 percent,

TABLE 5. Percent dry weight dietary composition of subyearling steelhead trout in tributaries of the Clearwater River, Idaho. Only those prey taxon which composed at least 2 percent of the diet of subyearling steelhead trout in one or more of the streams are included.

| | Stream | | | | | |
|---|---|---|---|---|---|---|
| | Bedrock Creek | Lapwai Creek | Jacks Creek | Mission Creek | Big Canyon Creek | Cottonwood Creek |
| **Aquatic Taxon** | | | | | | |
| Decapoda | | | | | | |
| Astacidae | —— | —— | —— | —— | 6.9 | —— |
| Plecoptera | | | | | | |
| Perlodidae | —— | 0.5 | —— | 1.3 | —— | 12.3 |
| Ephemeroptera | | | | | | |
| Baetidae | 13.6 | 5.7 | 6.9 | 30.7 | 6.5 | 19.2 |
| Heptageniidae | —— | 3.2 | —— | 1.1 | —— | —— |
| Unidentified | 1.4 | 2.6 | 1.6 | —— | —— | 1.3 |
| Trichoptera | | | | | | |
| Hydropsychidae | 13.2 | 8.6 | 9.3 | 9.2 | 16.4 | 11.7 |
| Unidentified | —— | 2.3 | 2.1 | —— | 0.5 | —— |
| Diptera | | | | | | |
| Chironomidae (L) | 12.5 | 16.3 | 19.5 | 7.2 | 36.1 | 17.7 |
| **Chironomidae (P)** | **1.2** | **3.7** | **7.1** | **7.4** | **11.4** | 5.5 |
| Chironomidae (A) | 0.4 | 0.4 | 2.3 | 3.7 | 2.2 | —— |
| Dixidae | —— | —— | 2.6 | —— | —— | —— |
| Tipulidae | —— | 7.3 | —— | 2.2 | —— | —— |
| Scatophagidae | —— | 0.9 | —— | —— | —— | 7.4 |
| Gastropoda | | | | | | |
| Physidae | —— | —— | 3.6 | —— | —— | 4.2 |
| Detritus | —— | —— | —— | —— | —— | 7.5 |
| Miscellaneous | —— | 4.7 | 0.8 | 6.5 | 1.3 | 3.1 |
| Total Aquatic | 42.3 | 56.2 | 55.8 | 69.3 | 81.3 | 89.9 |
| **Terrestrial Taxon** | | | | | | |
| Annelida | 12.6 | 1.5 | —— | —— | —— | —— |
| Arachnida | 10.8 | 3.2 | 9.9 | 2.7 | —— | 0.8 |
| Coleoptera | 32.5 | 3.3 | —— | 1.4 | 1.5 | —— |
| Dermaptera | —— | 0.6 | 9.2 | —— | —— | —— |
| Diptera | —— | 2.0 | 3.5 | 1.6 | 0.4 | —— |
| Hemiptera | 1.8 | 15.8 | —— | 0.9 | 5.6 | —— |
| Homoptera | —— | 14.7 | 14.0 | 15.4 | 7.9 | —— |
| Hymenoptera | —— | 2.7 | 7.6 | 8.7 | 3.3 | —— |
| Orthoptera | —— | —— | —— | —— | —— | 6.0 |
| Miscellaneous | —— | —— | —— | —— | —— | 3.3 |
| Total Terrestrial | 57.7 | 43.8 | 44.2 | 30.7 | 18.7 | 10.1 |

L—Larvae; P—Pupa; A—Adult.

$x = 15.8$ percent), baetids (5.7-19.2 percent, $x = 13.8$ percent), and hydropsychids (9.2-16.4 percent, $x = 11.4$ percent) were the primary aquatic invertebrates utilized by subyearling steelhead.

Diet overlap was estimated between the three species for each of the six streams. Because of the large contribution of detritus in the diet of speckled dace, diet overlap values between dace and Paiute sculpin (0.102-0.336, $x = 0.167$) and subyearling steelhead (0.062-0.250, $x = 0.161$) were very low (Table 6). Diet overlap between

TABLE 6. Dietary overlap values (C$\lambda$) among Paiute sculpin, speckled dace, and subyearling steelhead trout in tributaries of the Clearwater River, Idaho.

| Species | Stream | C$\lambda$ |
|---|---|---|
| Paiute Sculpin-Speckled Dace | Jack's Creek | 0.336 |
| | Lapwai Creek | 0.207 |
| | Big Canyon Creek | 0.128 |
| | Bedrock Creek | 0.120 |
| | Mission Creek | 0.111 |
| | Cottonwood Creek | 0.102 |
| | | $\bar{X} = 0.167$ |
| Paiute Sculpin-Steelhead 0+ | Cottonwood Creek | 0.869 |
| | Big Canyon Creek | 0.553 |
| | Jack's Creek | 0.552 |
| | Mission Creek | 0.532 |
| | Lapwai Creek | 0.517 |
| | Bedrock Creek | 0.489 |
| | | $\bar{X} = 0.584$ |
| Steelhead 0+-Speckled Dace | Jack's Creek | 0.250 |
| | Cottonwood Creek | 0.247 |
| | Big Canyon Creek | 0.178 |
| | Lapwai Creek | 0.145 |
| | Mission Creek | 0.085 |
| | Bedrock Creek | 0.062 |
| | | $\bar{X} = 0.161$ |

Paiute sculpin and subyearling steelhead was moderate (0.489-0.553) in five of the streams. Mutual predation on perlodids, baetids, hydropsychids, and chironomids by Paiute sculpin and steelhead in Cottonwood Creek resulted in the only high diet overlap value observed, 0.869.

#### Discussion

Collections of Paiute sculpin, speckled dace, and subyearling steelhead in the six Clearwater River tributaries generally reflected a similar pattern of distribution of these species in the basin as had been previously reported (Maughan 1976, Maughan and Saul 1979). Observations of microhabitat utilization indicated that during the period when collections were made all three species predominated in riffle areas. The utilization of riffle areas by Paiute sculpin (Jones 1972, Moyle 1976, Finger 1982), speckled dace (Moyle 1976, Schreiber and Minckley 1981, Baltz *et al.* 1982), and subyearling steelhead trout (Hartman 1965, Johnson and Ringler 1980) is well documented.

The most thorough examination of the diet of Paiute sculpin in a lotic environment was conducted in Sagehen Creek, California (Dietsch 1959). In Sagehen Creek benthic insects composed approximately 99 percent of the diet of Paiute sculpin with various prey taxa being seasonally dominant in the diet. Dietsch (1959) also found evidence that differences occurred between the diets of small (<59mm) and large (>80mm) sculpins.

Paiute sculpins in the Clearwater River tributaries, like those in Sagehen Creek, fed most heavily on aquatic insects, did not utilize terrestrial invertebrates, and except in Big Canyon Creek, were not piscivorous.

Because of the difficulty in separating algal from detrital material from the stomachs of speckled dace for dry weight analysis, both of these items were grouped as detritus. Jhingran (1948) found detritus to be a major component in the diet of speckled dace during summer. In the fall, dace have been shown to feed on unidentifiable fibrous material (Jhingran 1948) and algae (Li and Moyle 1976, Peden and Hughes 1981). However, most investigators examining the food habits of speckled dace describe the minnow as a predator on benthic insects (Jhingran 1948, Peden and Hughes 1981, Schrieber and Minckley 1981, Baltz *et al.* 1982). The principal benthic taxa that have been observed in the diet of dace are baetids, hydropsychids, and simuliids.

Subyearling steelhead (rainbow) trout feed most heavily on benthos during summer and early fall (Hannuksela 1973, Tippets and Moyle 1978, Johnson and Ringler 1980, Johnson 1981, Johnson and Johnson 1981). However, at least during diurnal periods, terrestrial invertebrates have been reported to comprise a substantial portion of the diet of subyearling steelhead (Johnson and Ringler 1980, Johnson 1981, Johnson and Johnson 1981). Although most of the diet of subyearling steelhead trout in Clearwater River tributaries was composed of autochthonous material, allochthonous prey items ($x = 34$ percent) contributed a considerable amount to the diet.

Only one of eighteen observations of diet overlap between Paiute sculpin, speckled dace, and subyearling steelhead trout in Clearwater River tributaries exceeded 0.56. Diet overlap values of 0.60 or more ar geenerally thought to indicate similar diets (Zaret and Rand 1971, Fuller and Stewart 1977). The data show that there is definite delineation in the foods eaten by these three species during diurnal periods when they occupy the same habitat in Clearwater River tributaries. This situation could prevail from shortly following steelhead emergence in June until terrestrial invertebrates become less available, possibly during mid to late autumn. Because of the scarcity of detrital and allochthonous material, diet overlap between Paiute sculpin, speckled dace, and subyearling steelhead overwintering in riffles would be expected to be higher than observed in this investigation. However, since food consumption rates are diminished at this time and standing crops of benthic insects are generally at their peak (Hynes 1970), competition for food between these benthic fishes might not be severe. By spring juvenile steelhead would no longer be present in high densities in riffles; they would be occupying areas having more cover.

Diet overlap between speckled dace and Paiute sculpin in Clearwater River tributaries was substantially lower than had been previously reported between dace and two other species of sculpins. Li and Moyle (1976) and Baltz *et al.* (1982) found a moderate overlap in diet between speckled dace with Pit sculpins (*C. pitensis*) and riffle sculpins (*C. gulosus*). These studies reported that both dace and sculpins fed similarly on benthic insects. Based upon the benthic composition of the diet of speckled dace, Jhingran (1948) judged that dace were competitors with subyearling chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout. However, the larger contribution of detrital material in the diet of speckled dace in this study led to low overlaps with both sculpin and steelhead. Hannuksela (1973) observed that the summer diets of mottled sculpins (*C. bairdi*) and juvenile rainbow trout were similar in a tributary of Lake Superior. Except for the larger contribution of allochthonous material in the diet of

steelhead in Clearwater River tributaries, results of the two studies are comparable.

Besides seasonal variation in diet composition, another factor to consider when evaluating either diet overlap or competition between fishes is diel feeding periodicity. Paiute sculpin are most active at night (Finger 1982) and are reportedly nocturnal feeders (Moyle 1976). Li and Moyle (1976) showed speckled dace to be primarily a diurnal feeder with peak feeding occurring at 2000 h. Johnson (1982) reported an identical peak (i.e., 1600-2000 h) for blacknose dace (*R. atratulus*) in a tributary of Lake Ontario. The food consumption of subyearling steelhead has been shown to increase substantially from 1200-2000 h with peak feeding occurring from 1600-2000 h in a tributary of the Salmon River, New York (Johnson and Johnson 1981). These data indicate that Paiute sculpin are nocturnal feeders whereas speckled dace and subyearling steelhead trout are principally diurnal feeders. Since the peak food consumption of Paiute sculpin occurs at a different time than either speckled dace or subyearling steelhead trout, competitive interactions for food may be reduced between these species and sculpins. The large contribution of terrestial invertebrates in the diet of subyearling steelhead suggests that this species is feeding heavily on drift. Conversely, the detrial and benthic components in the diet of speckled dace indicate that this species is primarily a benthic forager. Differences in foraging areas of dace and steelhead therefore could offset any competitive interactions created by diurnal feeding peaks for both species.

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# Relationships Between Fecal and Rumen Analyses for Deer Diet Assessments in Southeastern Alaska

**Abstract**

Rumen and fecal samples obtained from 13 Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) from 21 January through 13 March 1981, were analyzed to determine percentage dry weight composition of plant species and forage classes. Mean percentage similarity of the two types of samples was 65 and 77 percent for plant species and forage classes, respectively. Spearman's rank correlation coefficients were 0.56 and 0.66 ($P<0.05$ for both), respectively. Forbs and ferns were consistently more abundant in rumen than fecal samples, while graminoids, mosses, conifers, and lichens were more abundant in fecal than rumen samples.

## Introduction

The composition of diets selected by wild, free-ranging ungulates is difficult to determine. Such a determination is important for evaluating the nutritional quality of diets and for understanding animal-habitat relationships. Direct methods of determining diet composition, such as esophageal fistula (Veteto *et al.* 1972) or bite count (Wallmo and Neff 1970) methods, can be used only with tame, or at least very human-tolerating, animals. Diet determinations for wild, free-ranging ungulates must rely on indirect methods, such as forage site examinations (Cole 1959), stomach analysis (Korschgen 1962, Dirschl 1962), or fecal analysis (Croker 1959, Storr 1961). Forage site examinations suffer from the obvious problems of measuring what has been eaten and the site-specific nature of the data. Stomach and fecal analyses are the most commonly employed methods of determining diet comosition of wild, free-ranging ungulates.

The principal advantage of stomach analysis is that much of the contents consists of macroscopic fragments that can be identified readily with minimal equipment. The principal disadvantages are that animals must be killed or captured to obtain samples and that forages that are readily digested or rapidly passed from the stomach tend to be under-represented while those that are slowly digested and/or passed tend to be over-represented. The latter is a special problem with rumen analysis (Bergerud and Russell 1964, Gaare *et al.* 1977). That technique results in over-estimation of the poorer quality forages and underestimation of the better forages. The principal advantage of fecal analysis is that fecal samples are relatively easy to obtain and do not require handling of animals; hence, it is possible to obtain large sample sizes without disturbing the study population. The principal disadvantages are that plant fragments must be identified microscopically, thus requiring extensive experience, and that highly digestible and/or poorly identifiable forages tend to be under-represented, while poorly digestible and/or highly identifiable forages tend to be over-represented in the diet determination (Adams *et al.* 1962, Slater and Jones 1971, Dearden *et al.* 1975, Havstad and Donart 1978).

The purpose of this study was to compare the results of analyses of rumens and feces obtained from Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) in southeastern Alaska. It was not possible to compare these results with known diets, since such data were not available. Still, it is important to have some understanding of how rumen and fecal results differ to enable better comparisons with results reported for one or the other method in the literature. This study offers a better basis for appraising the results from either method or from their use in combination. No such comparison has been made previously for Sitka black-tailed deer or for the forages of southeastern Alaska or coastal British Columbia.

## Methods

The data were obtained as paired rumen and fecal samples from 13 deer shot from 21 January through 17 March 1981. All seven males and six females ranging from fawns to very old animals (10+ yrs), were collected in the vicinity of Admiralty Island (Hawk Inlet and Winning Cove) and northeastern Chichagof Island (Tenakee Inlet and Whitestone Harbor), approximately latitude 58° N, longitude 135° W. The winter of 1980-81 was very mild, with little or no snow at sea level during the time deer were collected. Animals were obtained by hunting in old-growth forest, beach-fringe, muskegs, and one recent clearcut. Animals were shot as encountered. From each animal, the rumino-reticulum was excised whole, and approximately 20 fecal pellets were obtained from the rectum. Materials were frozen and returned to the laboratory. Two 100-200 ml samples were obtained from each completely thawed rumen for determination of plant species composition. The samples were collected by thoroughly mixing the rumino-reticular contents and quickly removing a sample with a tubular suction device. Such samples were found to be highly uniform in terms of dry matter content, particle size distribution, and species composition (D. E. Spalinger, unpublished report on file at Forestry Sciences Laboratory, Juneau). The two samples from each rumen were combined and washed through standard soil screens. All material that did not pass through a 2.00 mm screen was retained, oven dried, and separated by plant species. The rumen composition was expressed as percentage oven-dry weight of each plant species. Fecal samples were prepared by mixing in a Waring blender and washing over a 0.074 mm

screen. Five microscope slides per sample were prepared according to procedures described by Sparks and Malechek (1968). Approximately three identifiable plant fragments occurred in each microscope field of view at 100 power magnification. Frequency of occurrence of each plant species in each of 20 microscope fields per slide (100 fields per sample) was determined and converted to percentage relative density (Sparks and Malecheck 1968), which is assumed to be directly proportional to percentage ovendry weight.

The treatment of these data as paired-samples requires the assumption that each deer consumed a constant diet during the approximately one week period preceding its collection. Drastic shifts in the diet could result in very different forages being represented in the upper and lower digestive tracts. This assumption of constant diet detracts from statistically valid paired-sample comparisons; but it permits examination of relationships which would not be possible by treating the data as two independent sets.

The data were analyzed in terms of plant species and forage classes. The overall mean compositions of the rumen and fecal samples were compared by calculating their percentage similarity ($PS$) by Czekanowski's Index (Feinsinger *et al.* 1981):

$$PS = \sum_i \min (p_i, q_i) \times 100,$$

where $p_i$ is the proportional dry weight of item $i$ in the rumen, and $q_i$ is the proportional dry weight of item $i$ in the feces. Spearman's rank correlation coefficient also was calculated for the two sets of results. Rumen-fecal relationships within forage classes were examined by plotting for each forage class the paired-sample results from each of the 13 deer.

#### Results

Rumen and fecal methods yielded generally similar results, both in terms of plant species composition and forage class composition (Table 1). The percentage similarities were 65 and 77 percent, respectively. Spearman's rank correlation coefficients were 0.56 and 0.66 ($P<0.05$ for both), respectively. Herb-layer, evergreen half-shrubs, especially *Cornus canadensis*, were the most abundant foods in both rumen and fecal material. Conifers, especially *Chamaecyparis nootkatensis* and *Tsuga* spp., were next most abundant, and graminoids and mosses were least abundant. It also is evident, however, that some forages were consistently over/under-represented in one technique relative to the other. Forbs and ferns were consistently more abundant in rumen than fecal samples, while graminoids, mosses, and to a lesser extent conifers, were more abundant in fecal than rumen samples (Fig. 1).

Among the forbs, *Lysichiton americanum* and *Coptis aspleniifolia* were consistently very poorly represented in the fecal samples. Both are highly digestible (*L. americanum* was very young with tender shoots) (Hanley and McKendrick 1983). *Tiarella trifoliata* appeared to be equally well represented in fecal and rumen samples. The only paired sample that had a higher composition of forbs in the feces than the rumen was a sample that was especially high in *T. trifoliata* (17 percent in feces, 12 percent in rumen) and contained no other forbs. In all 12 of the other paired samples, forbs were under-represented in the feces relative to the rumen.

Herb-layer, evergreen half-shrubs, especially *Cornus canadensis*, tended to be under-

TABLE 2. Mean percentage composition, range, and percentage frequency of forage in 13 rumen and fecal samples from Sitka black-tailed deer collected during 21 January through 17 March 1981.

| FORAGE CLASS/Species | Feces | | | Rumens | | |
|---|---|---|---|---|---|---|
| | Percentage composition | Range | Percentage frequency[1] | Percentage composition | Range | Percentage frequency[1] |
| FORBS | | | | | | |
| **Coptis asplenifolia** | 1 | 0-4 | 69 | 9 | 0-19 | 92 |
| **Lysichiton americanum** | t[2] | 0-1 | 38 | 4 | 0-19 | 69 |
| **Moneses uniflora** | t | 0-t | 8 | 0 | 0 | 0 |
| **Pyrola secunda** | t | 0-t | 38 | 0 | 0 | 0 |
| **Tiarella trifoliata** | 2 | 0-17 | 62 | 2 | 0-12 | 85 |
| HERB-LAYER, EVERGREEN HALF-SHRUBS | | | | | | |
| **Cornus canadensis** | 24 | 2-46 | 100 | 34 | 14-54 | 100 |
| **Rubus pedatus** | 11 | 1-37 | 100 | 7 | 1-32 | 100 |
| **Vaccinium** spp.[3] | t | 0-1 | 46 | 1 | 0-3 | 92 |
| SHRUB LEAVES | | | | | | |
| **Empetrum nigrum** | t | 0-3 | 23 | t | 0-t | 15 |
| **Ledum palustre** | 9 | 0-42 | 62 | 3 | 0-19 | 46 |
| **Oxycoccus microcarpus** | t | 0-1 | 31 | 0 | 0 | 0 |
| **Phyllodocae** spp. | 0 | 0 | 0 | t | 0-6 | 8 |
| **Vaccinium vitis-idaea** | 0 | 0 | 0 | t | 0-2 | 38 |
| unknown | t | 0-2 | 46 | 4 | 0-23 | 46 |
| SHRUB STEMS | | | | | | |
| **Alnus** spp. | t | 0-t | 8 | 0 | 0 | 0 |
| **Vaccinium** spp. | 5 | t-16 | 100 | 4 | 0-10 | 92 |
| unknown | 1 | 0-5 | 69 | 6 | 0-17 | 92 |
| CONIFERS | | | | | | |
| **Chamaecyparis nootkatensis** | 14 | 0-51 | 69 | 11 | 0-47 | 54 |
| **Picea sitchensis** | 0 | 0 | 0 | t | 0-t | 23 |
| **Pinus contorta** | t | 0-3 | 15 | 0 | 0 | 0 |
| **Tsuga** spp. | 15 | 1-67 | 100 | 7 | t-26 | 100 |
| GRAMINOIDS[4] | 2 | 0-7 | 85 | t | 0-t | 38 |
| FERNS[5] | 2 | 0-18 | 31 | 4 | 0-38 | 38 |
| LICHENS | | | | | | |
| **Lobaria** spp. | 5 | 0-44 | 85 | 0 | 0 | 0 |
| **Ushea** spp./**Alectoria** spp. | t | 0-1 | 38 | 1 | 0-3 | 77 |
| other lichens | 0 | 0 | 0 | 2 | 0-14 | 77 |
| MOSSES | | | | | | |
| **Hylocomium** spp./ **Rhytidiadelphus** spp. | 4 | 0-16 | 100 | t | 0-1 | 69 |
| **Sphagnum** spp. | 1 | 0-1 | 69 | t | 0-t | 15 |
| ALGA (**Fucus furcatus**) | 3 | 0-25 | 69 | 3 | 0-17 | 77 |

[1]Presence or absence in 13 samples.

[2]t=trace=<0.5 percent

[3]decumbent, evergreen variety.

[4]primarily **Elymus** spp. and **Carex** spp.

[5]primarily **Dryopteris dilatata.**

represented in the fecal samples relative to the rumen samples when their abundance was low in both fecal and rumen samples. Shrub leaves consisted primarily of *Ledum palustre*, which tended to be over-represented in the fecal samples relative to rumen samples. A high proportion of unknown leaves (23 percent) in one rumen sample was responsible for the anomolously high data point for shrub leaves in Figure 1. No clear relationships were evident in the comparison involving shrub stems.

Conifers, graminoids, lichens, and mosses tended to be over-represented in the fecal samples relative to rumen samples. Among the conifers, only *Chamaecyparis nootkatensis* and *Tsuga* spp. were represented to any important degree. Ferns were under-represented

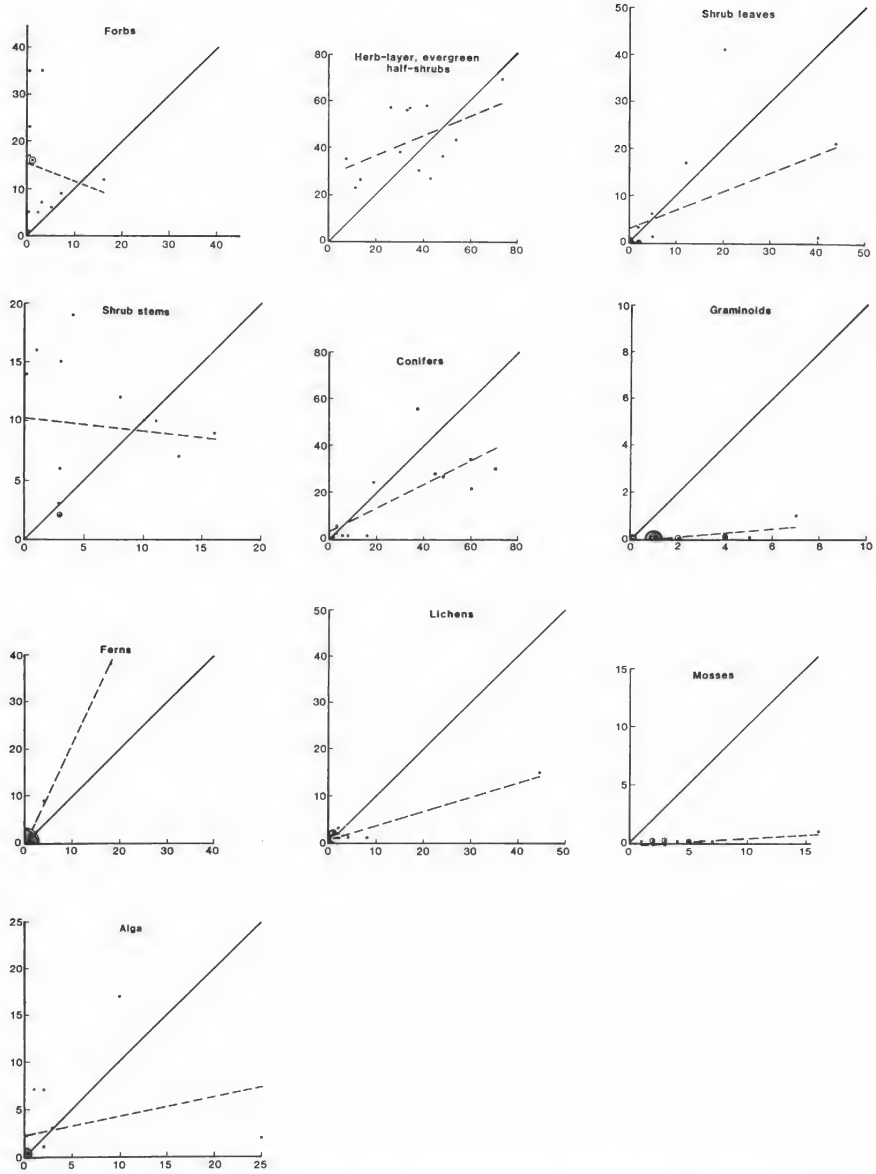


Figure 1. Percentage composition of 13 paired rumen and fecal samples (solid circles), plotted for each of 10 forage classes. Solid line indicates 1:1 relationship; broken line indicates linear regression best-fit relationship. Horizontal axis is percentage composition in feces; vertical axis is percentage composition in rumens.

in the feces relative to rumens, probably due to very high digestibility (ferns were primarily *Dryopteris dilatata* and were in the tender, young, fiddle-head stage at the

time they were eaten). No clear relationships were evident in the comparison involving rockweed alga (*Fucus furcatus*).

### Discussion

Several general relationships are evident and provide valuable insight into the relative merits of rumen and fecal analyses for deer diet assessments in southeastern Alaska in winter and early spring. Forbs and ferns were under-represented, while graminoids, mosses, and conifers were over-represented in fecal analysis relative to rumen analysis. Similar results have been observed by other investigators (Anthony and Smith 1974, Dearden *et al.* 1975, Kessler *et al.* 1981) and have been related to differential digestibility and identifiability of forages. Highly digestible forages also are under-represented in rumen analysis relative to actual diet composition (Gaare *et al.* 1977). Both techniques tend to over-estimate diet constituents of poorer quality (i.e., digestibility) and underestimate those of higher quality.

In a more general sense, however, both techniques provided rather similar results. Fecal analysis has a practical advantage over rumen analysis in that animals do not need to be killed or captured to obtain fecal samples. The ability to obtain greater sample sizes with fecal analysis than with rumen analysis and the ability to obtain fecal samples repeatedly from the same study area without disturbing the study population are important considerations to be made when choosing between the two techniques. Neither technique yields actual diet composition data; both techniques have biases. These biases must be kept in mind when designing experiments and evaluating fecal or rumen composition data in terms if diet composition.

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# A Survey of Idaho Science Teachers

**Abstract**

The survey results reported in this paper describe science education in Idaho. The paper is divided into four parts. The first part describes the organization of science departments within secondary schools. Part two describes the typical Idaho science teacher including years of experience, qualifications, professional activity, the number and types of courses they teach, and extracurricular assignments. Part three describes the science curriculum in Idaho secondary schools. Part four describes the facilities and materials available in the Idaho schools including the text used.

## Introduction

The Idaho Science Teachers' Association sponsored the first comprehensive survey of Idaho Science teachers in the spring of 1982. The results are summarized in this report. The data were divided into the categories: organization of science departments, the Idaho Science Teacher, curriculum, and facilities and materials.

An 11 item survey was mailed to all of the science teachers (grades 7-12) in Idaho during the spring of 1982 (see Appendix A). In this study science teachers were defined as those teachers who teach one or more science classes. Science classes include any of the life, physical, and earth sciences. The Idaho State Department of Education supplied the mailing list of science teachers in the state. The list was one year out of date so those receiving the survey were asked to share them with new teachers. Returned surveys indicated that many were passed on or copied, allowing those who did not receive them to respond. The initial mailing was sent to 706 teachers. A total of 231 were returned for a response rate of 33 percent. The return represented 76 percent of the school districts with secondary schools (80/105) and 61 percent of the secondary schools in the state (127/207). Twenty three of the 127 schools represented in the returns were classified as small (less than 50 students per grade). All of these schools are rural by any one of several definitions of rural schools (Sher and Rosenfled 1977).

## Organization of Science Departments

The first set of data was used to formulate a picture of the organization of science departments within the secondary schools. Sixty percent of the schools represented have a designated department chair. As one would expect, small schools were more likely to not have a designated department head, although almost half of the one, two, and three teacher departments had department heads. The average science faculty size for those

schools with a department head was 4.5, while those without a head had an average science faculty of 2.5. The average science faculty size for all schools was 3.8.

#### Idaho Science Teachers

The second set of data was used to develop a profile of the Idaho science teacher. The average Idaho science teacher has taught 10.9 years. Idaho has more of its less experienced teachers at the lower grade levels. The average years of experience for senior high teachers was 12.0 compared to 10.4 for the junior high school. Many Idaho schools (24 in this study) are junior/senior high combinations. The most dramatic individual differences in years of experience were found in these schools, where the average was 8 years of experience. The individual in this survey with the most years of experience (33 years) taught in a junior/senior high school. Without that person in the total the average experience for teachers in junior/senior high combinations would have been 7 years. The average years of experience for teachers in small/rural schools was 8.7 years.

Idaho like most states is experiencing a shortage of science teachers (Heikkinen 1982, Guthrie and Zusman 1982). Three items on the survey were used to determine how the teaching positions were being filled. Respondents were asked to indicate the areas in which they were certified, their major(s), and the courses they were teaching. All but 10 of the respondents appeared to be certified to teach the courses they were assigned.

The teachers' majors were also used to determine qualifications. When the majors were compared with teaching duties, 25 percent of the teachers appeared to be misassigned in one of two ways. The first group was made up of those individuals who majored in a science, such as biology, but were teaching another science, such as physics. The second group was composed of those who majored in nonscience disciplines. This second group accounted for two thirds of the misassigneds. In the second group the most common major was physical education followed closely by social sciences and agriculture.

Some examples of the most blatant misassignments follow. One teacher held an elementary certificate, with endorsements in English and social studies, and was teaching three classes of seventh grade life science and three classes of seventh grade mathematics. A mathematics major with endorsements in mathematics and social studies was teaching earth science; a social studies major was teaching life science and a physical education major with endorsements in physical education and health was teaching physiology and biology. It is probable that even more glaring misassignments exist and were not reported.

The problem of misassignments was greater in the small/rural schools. As many as 83 percent of the teachers were misassigned in one way or another for some of the classes they taught.

Thirty five percent of the teachers surveyed indicated membership in a professional organization and only 13 percent belonged to more than one organization. Only 21 percent of the teachers in small/rural schools belonged to professional organizations. The organization with the largest membership was the Idaho Science Teachers Association with 25 percent of the teachers surveyed. Sixteen percent belonged to the National Science Teachers Association, with small numbers belonging to many different more specialized organizations, such as the National Association of Biology Teachers or the American Association of Physics Teachers.

Only 28 percent of the teachers had a single class to prepare. Most of the teachers with a single preparation taught the basic science courses (life, physical, earth ,and biology). Only five teachers in the survey had a single preparation in chemistry, physics or an advanced science. Fifty seven percent of the teachers had two or three preparations. Fifteen percent had four or more preparations.

Because of small enrollments, teachers in small/rural schools teach more subjects. None of the small/rural school teachers in this survey had a single class to prepare, while 57 percent of them had four or more preparations.

Ninety five teachers taught courses other than science. The other subjects most commonly taught were mathematics and health (20 percent of the teachers surveyed also taught mathematics). A wide variety of other subjects were taught and the distribution was across the curriculum.

In addition to the courses they teach, 74 percent of the respondents had one or more extracurricular assignments. Of those with extracurricular assignments, 55 percent had one assignment, 23 percent had two assignments, and 22 percent had three or four assignments. Fifty four percent of the assignments were in athletics and coaching, 27 percent sponsored clubs, and 13 percent were class advisors. Other assignments were varied and included such activities as being department head, driving a bus, driver education, and conducting inservice training for the school district.

#### Curriculum

The typical sequence in which science courses are taught in Idaho schools is: life science in seventh grade—77 percent of the schools, physical science in eight grade—47 percent of the schools (another 30 percent of the schools taught it in the ninth grade), earth science in ninth grade—47 percent of the schools, biology in tenth grade—90 percent of the schools, chemistry in eleventh grade—59 percent of the schools (another 37 percent taught it in eleventh or twelfth grade), and physics in the twelfth grade—56 percent of the schools (another 39 percent taught it in eleventh or twelfth). General science was taught in only 14 of the 127 schools responding and was typically taught in the junior high school.

A large variety of sciences were offered at the advanced level. Advanced sciences were courses, usually taught at the eleventh and twelfth grades, designed to allow students interested in the sciences choices of science electives in addition to the traditional earth science, biology, chemistry, and physics sequence. Those most commonly taught, in descending order, were: physiology, advanced biology, ecology, advanced chemistry, horticulture, and geology.

#### Facilities and Materials

A series of items on the survey were designed to gather information about the facilities available for teaching science. These data are summarized in Table 1. Sixty-one percent of the teachers indicated that their classrooms were standard science laboratories and 66 percent thought that their facilities were adequate.

Table 2 lists the most widely used texts for the basic courses. These data were compiled by schools and not by individual teachers. The most commonly used texts in Idaho are basically the same as those most commonly used in the nation as identified in the Science Education Databook (1980). The main exception is the Holt junior high school

TABLE 1. This table gives the percentage of classrooms that have specific quantities of common laboratory equipment available. In addition to the percentages for all science classrooms, the percentages for specific kinds of science classrooms are also given. Some classrooms are included in more than one of the pecific classroom totals. For example, if a teacher taught both life science and chemistry, the data for that classroom would be included in both the life sciences parts of the table and the chemistry parts.

| Equipment | Type of classroom | Number of items available | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 1-5 | 6-10 | 11-15 | 16-20 | 21-25 | 25 or more |
| Running Water Outlets | Earth Science | 14 | 45 | 18 | 11 | 9 | 3 | |
| | Life Science | 13 | 56 | 19 | 8 | 2 | 1 | 1 |
| | Chemistry | 4 | 15 | 35 | 20 | 15 | 9 | 2 |
| | Physics/ Phy. Science | 12 | 39 | 24 | 16 | 5 | | 4 |
| | All classrooms | 15 | 53 | 18 | 8 | 5 | 1 | 1 |
| Electrical Outlets | Earth Science | | 22 | 28 | 24 | 13 | 9 | 4 |
| | Life Science | | 20 | 24 | 21 | 16 | 4 | 15 |
| | Chemistry | | 13 | 24 | 22 | 22 | 9 | 11 |
| | Physics/Phy. Science | | 22 | 26 | 21 | 15 | 6 | 10 |
| | All classrooms | | 25 | 26 | 18 | 14 | 6 | 11 |
| Gas Outlets | Earth Science | 34 | 18 | 16 | 7 | 13 | 4 | 6 |
| | Life Science | 39 | 21 | 16 | 6 | 9 | 3 | 5 |
| | Chemistry | 7 | 7 | 13 | 15 | 28 | 9 | 22 |
| | Physics/Phy. Science | 22 | 19 | 17 | 15 | 11 | 5 | 11 |
| | All classrooms | 32 | 20 | 16 | 8 | 12 | 3 | 8 |
| Microscopes | Earth Science | 42 | 17 | 17 | 11 | 8 | 3 | 3 |
| | Life Science | 9 | 9 | 13 | 24 | 21 | 9 | 16 |
| | Chemistry | 44 | 9 | 27 | 4 | 4 | 7 | 4 |
| | Physics/Phy. Science | 32 | 16 | 22 | 12 | 6 | 4 | 7 |
| | All classrooms | 30 | 12 | 12 | 18 | 12 | 6 | 10 |
| Balances | Earth Science | 9 | 43 | 21 | 21 | 1 | 4 | |
| | Life Science | 24 | 47 | 19 | 7 | 1 | 2 | 1 |
| | Chemistry | | 42 | 40 | 16 | 2 | | |
| | Physics/Phy. Science | 4 | 43 | 30 | 16 | 5 | | 2 |
| | All classrooms | 17 | 40 | 23 | 14 | 3 | 3 | 1 |
| Fume Hoods | Earth Science | 53 | 47 | | | | | |
| | Life Science | 80 | 20 | | | | | |
| | Chemistry | 22 | 78[1] | | | | | |
| | Physics/Phy. Science | 59 | 51 | | | | | |
| | All classrooms | 71 | 29[2] | | | | | |

[1]17 percent of the chemistry classrooms have more than one fume hood.

[2]Less than 4 percent of all science classrooms have more than one fume hood.

series which was not yet published at the time of the 1977 study cited in Databook. Although all of these texts are on the state's Textbook Adoption Commission's list of approved texts, only 57 percent of the schools were using the most recent edition and 61 percent of the schools were using texts two or more editions out of date. The most serious problem was in physics where 64 percent of the schools were using texts that were not the most recent edition and 36 percent of the classrooms had texts two or more editions out of date, some as old as 1964.

### Conclusion

The foregoing data gave a statistical picture of teaching science in Idaho. The following is intended to be more qualitative and will reflect on some of the areas of concern. Science teachers in Idaho seem to be operating under burdens that make their jobs difficult. Although the average years of experience is similar to that in the other states, the younger, less-experienced, teachers are placed in the most demanding situations of teaching in

TABLE 2. The most commonly used science textbooks in Idaho classrooms.

| Text | Publisher | Author(s) | Percent Using |
|---|---|---|---|
| | Life Science (52 Schools) | | |
| Focus on Life Science | Merrill | Heimler, Lockard | 25 |
| Challenges to Life Science | Webster-McGraw | Smallwood | 21 |
| Holt Life Science | Holt | Ramsey | 13 |
| | Biology (59 Schools) | | |
| Modern Biology | Holt | Otto, Towle | 49 |
| Scotts Forsman Biology | Scott Forsman | Slesnick, et al | 20 |
| Biology: Living Systems | Merrill | Oram, et al | 14 |
| | Anatomy/Physiology (15 Schools) | | |
| Modern Human Physiology | Holt | Morison | 60 |
| | Physical Science (53 Schools) | | |
| Focus on Physical Science | Merrill | Heimler, Price | 25 |
| Holt Physical Science | Holt | Ramsey | 15 |
| Introductory Physical Science | Prentice Hall | Haberschaim, et al | 15 |
| | Physics (37 Schools) | | |
| Modern Physics | Holt | Williams | 51 |
| Physics: Principles and Problems | Merrill | Murphy, Smoot | 24 |
| | Chemistry (37 Schools) | | |
| Chemistry: A Modern Course | Merrill | Smoot, et al | 39 |
| Modern Chemistry | Holt | Metcalfe | 38 |
| | Earth Science (54 Schools) | | |
| Focus on Earth Science | Merrill | Bishop, et al | 24 |
| Modern Earth Science | Holt | Ramsey | 13 |
| Holt Earth Science | Holt | Ramsey | 11 |
| Earth Science | Allyn Bacon | Namowitz, Stone | 11 |

junior high schools and small rural schools. Although only 4 percent of those responding appeared to not have the proper endorsements for teaching science, 25 percent were being asked to teach subjects in which they did not major in college. Almost three-fourths of the teachers had to prepare for more than one course (more than half of these were nonscience courses). In addition, three-fourths of the teachers had extra-curricular assignments. The almost total lack of participation in professional science teacher organizations at the national level is distressing, since organizations like these provide the only professional contacts for most teachers.

The science curriculum in Idaho schools is similar to that found in most states with the typical sequence being life science, physical science, earth science, biology, chemistry, and physics. This is only the typical sequence; as many as half of the schools may follow another sequence. In a mobile society like ours, this causes serious problems for students as they move from school to school, even within the same state.

The most serious problem facing science teachers in Idaho is the lack of facilities and materials. With more than half of the classrooms not adequately set up for teaching science as a laboratory course and more than one third of them using out of date editions of texts, preparing Idaho's children for a technological future is a difficult task.

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**Appendix A**

**Idaho Science Teachers Survey**

Please complete the survey as best you can. If explanation is warranted, write in the space next to the question or add an additional sheet of paper. Please send completed survey to Steve Chin, Blackfoot Junior High School, Rt. 3, Box 429, Blackfoot, Idaho 83221. Thank you.

1. School name: _____ Mid Sch. Jr. Hi. Sr. Hi.

2. School District name and number: _____

3. Number of science teachers in your school: _____

4. Is there a designated science department chairperson? yes no

5. Certification:

| Check the area/s that you are certified to teach | | Check the area/s in which you majored in college |
|---|---|---|
| _____ | Physics | _____ |
| _____ | Chemistry | _____ |
| _____ | Biology | _____ |
| _____ | Geology | _____ |
| _____ | Biological Science | _____ |
| _____ | Earth Science | _____ |
| _____ | Physical Science | _____ |
| _____ | General Science | _____ |
| _____ | Agricultural Science | _____ |
| _____ | Health Science | _____ |
| _____ | Math | _____ |
| _____ | Others (Please Specify) | _____ |
| _____ | | _____ |

| Indicate the number of classes you teach in each of the following areas. | | Indicate the grade level of the majority of the students in each of the classes you teach. |
|---|---|---|
| _____ | Physics | _____ |
| _____ | Chemistry | _____ |
| _____ | Physiology | _____ |
| _____ | Botany | _____ |
| _____ | Geology | _____ |
| _____ | Ecology | _____ |
| _____ | Health Science | _____ |
| _____ | Biology | _____ |
| _____ | General Science | _____ |
| _____ | Earth Science | _____ |
| _____ | Physical Science | _____ |
| _____ | Life Science | _____ |
| _____ | Math | _____ |
| _____ | Others (Please Specify) | _____ |
| _____ | | _____ |

7. Textbooks: Please indicate the text(s) that you use in each of the courses you teach.

| Course | Title of Text | Edition Date |
|---|---|---|
| _____ | _____ | _____ |
| _____ | _____ | _____ |

8. How many years of teaching experience do you have prior to the current school year? _____

9. Facilities: Please check the facilities that you have available in your room.
   - _____ Do you consider your room a standard science laboratory?
   - _____ Running water (How many faucets? _____)
   - _____ Electrical outlets (How many? _____)
   - _____ Gas outlets (How many? _____)
   - _____ Microscopes (How many? _____)
   - _____ Balances (How many? _____)
   - _____ Fume Hood (How many? _____)
   - _____ Adequate equipment to conduct a laboratory oriented program?

Comments, if any.

_____

10. Please indicate your membership in local, regional, and/or national science organizations.

11. Please indicate any extracurricular activity/activities you sponsor (including coaching duties).

Your contribution of time and return postage is greatly appreciated.

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# Habitat Used by Shrews in Southeastern Montana

## Abstract

Dwarf shrews (*Sorex nanus*), masked shrews (*Sorex cinereus*), and merriam shrews (*Sorex merriami*) were most abundant in riparian and sagebrush-grass habitat types in southeastern Montana. Litter cover was greater in areas occupied by shrews than in areas without shrews. Microhabitat humidity, as related to litter cover and vegetation structure, appears to affect shrew distribution in southeastern Montana.

## Introduction

Shrew (Soricidae) habitat quality has been based on the numbers of shrews caught within a particular vegetation type (Buckner 1964, Spencer and Pettus 1966, Long 1972, Wrigley *et al.* 1979). Most authors have described shrew occurrences without quantifying the vegetation. Quantitative vegetation information would be valuable for recognizing shrew habitats which could become endangered from surface mining or livestock grazing in southeastern Montana.

This paper presents information on shrews captured in southeastern Montana and quantification of the vegetation around those capture points. We assumed that capture sites were representative of habitats occupied by shrews in the study area.

## Study Area and Methods

The study area was west of Alzada, Carter County, Montana, along the northern edge of the Black Hills. Elevations ranged from 1036 to 1128 m. A sagebrush-grass vegetation type occupied 74 percent of the study area. The most abundant plants were big sagebrush (*Artemisia tridentata*) and buffalograss (*Buchloe dactyloides*). Riparian areas, primarily wooded stream bottoms, encompassed 14 percent of the area. Major plants, there, were boxelder maple (*Acer negundo*) and snowberry (*Symphoricarpos* spp.).

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A pine forest type covered 8 percent of the area consisting of ponderosa pine (*Pinus ponderosa*) and western wheatgrass (*Agropyron smithii*).

Four sites of both the sagebrush-grass and riparian types were selected for study. Two sites of the pine type were examined.

Twenty pitfall traps were placed at 10 m intervals along a transect at each site. Pitfall traps were made by sinking a number 10 metal food can flush with ground level. A small board was placed over the top for cover, leaving space underneath for animals to enter. Five meters away, and parallel to the pitfall trap line, a series of 20 Sherman live traps were placed at 10 m intervals. Trap lines were sampled for three consecutive nights each month, April through October, during 1979 and 1980.

Vegetation characteristics, where trap lines were established, were estimated during summers 1979 and 1980. Percent canopy cover, by species, was determined by methods outlined by Daubenmire (1959). In each area, three parallel 50 m line transects were established approximately 30.5 m apart. Canopy cover was estimated in 50 quadrats (2 x 5 dm) spaced at 1 m intervals along each transect. Correlation analysis was used to relate shrew and vegetation abundance.

### Results and Discussion

All shrews were captured in pitfall traps. During the first year of study, dwarf shrews (*Sorex nanus*) were most abundant and were captured in sagebrush-grass and riparian habitats (Table 1). Masked shrews (*S. cinereus*) were present only in riparian areas.

TABLE 1. Number of shrews captured, by species and habitat type, during two years of study in southeastern Montana.

| | Riparian | | Sagebrush | | |
|---|---|---|---|---|---|
| Species | 1979 | 1980 | 1979 | 1980 | Total |
| **Sorex cinereus** | 2 | 8 | 1 | 0 | 11 |
| **S. nanus** | 4 | 2 | 2 | 0 | 8 |
| **S. merriami** | 0 | 0 | 1 | 0 | 1 |
| Total | 16 | | 4 | | |

TABLE 2. Mean (± SE) percent canopy cover[1] of bare ground, litter, and major plant categories in habitat types where shrews were captured and not captured in southeastern Montana.

| | Shrews | | No shrews | |
|---|---|---|---|---|
| Categories | Riparian | Sagebrush | Sagebrush | Pine |
| Bare ground | 8 ± 1 | 22 ± 2 | 20 ± 2 | 12 ± 2 |
| Litter | 30 ± 3 | 25 ± 4 | 15 ± 1 | 46 ± 6 |
| Grasses and Carices | 39 ± 14 | 35 ± 13 | 45 ± 10 | 22 ± 4 |
| Forbs | 9 ± 4 | 5 ± 3 | 4 ± 1 | 5 ± 2 |
| Shrubs | 18 ± 6 | 3 ± 1 | 13 ± 2 | 2 ± 1 |
| Total Cover | 64 ± 5 | 49 ± 4 | 64 ± 2 | 37 ± 8 |

[1]Two-dimensional cover values.

Merriam shrews (*S. merriami*) were the least abundant and were captured only in sagebrush-grass type. Masked shrews were most abundant during the second year of study. Both masked and dwarf shrews were found only in riparian habitat. No Merriam shrews were captured during the second year of study. Habitat relations of Merriam shrews were not analyzed because of limited sample size. A total capture of 20 shrews

with an effort equal to 14,400 trap nights indicated that shrews are relatively rare in southeastern Montana. All captured shrews were cataloged and deposited in the United States Fish and Wildlife Service Museum, Fort Collins, Colorado.

Generally, riparian habitat occupied by shrews was higher in total cover and shrub cover than sagebrush-grass areas with shrews, and pine forest areas. Riparian habitat with shrews and sagebrush-grass areas without shrews were equal in all categories except litter, which was greater in riparian habitat. Litter was also higher in sagebrush-grass areas with shrews than in sagebrush-grass areas without shrews. Cover of big sagebrush was greater in sagebrush-grass areas without shrews than with shrews. Forb and grass cover was similar in all habitat types (Table 2).

Dwarf shrews were significantly associated with coverage of common dandelion (*Taraxicum officinnle*), common timothy (*Phleum pratense*), rose (*Rosa* spp.), and macoun wildrye (*Elymus macouni*) (Table 3). All of these plants are abundant adjacent

TABLE 3. Correlations among shrew abundance and plant species cover.

| Plant species | Sorex nanus | Sorex cinereus |
|---|---|---|
| **Bromus japonicus** | 0.151 | 0.242 |
| **Taraxacum officinale** | 0.737* | 0.091 |
| **Opuntia polyacantha** | 0.072 | 0.299 |
| **Parmelia chlorachora** | 0.104 | 0.433 |
| **Phleum pratense** | 0.716* | 0.089 |
| **Rosa** spp. | 0.718* | 0.157 |
| **Elymus macouni** | 0.717* | 0.095 |
| **Fraxinus pennsylvanicus** | 0.633* | 0.180 |

*$P < 0.05$.

to streams. Masked shrew abundance was not significantly correlated with any measured plant species.

Litter cover (dead plant parts) appears to be the important habitat component. In sagebrush-grass areas, transects where shrews were caught possessed more litter than those without shrews. Litter cover was also abundant in riparian habitat. Litter in the pine forest type was relatively less moist than that found in riparian or sagebrush-grass types. Black and Hooven (1974) noted that shrews left areas where wildfire had burnt off litter.

The results of this study show that shrews in southeastern Montana are most abundant in riparian habitat, but may also occupy drier sites such as sagebrush-grass areas. Wrigley *et al.* (1979) drew the same general conclusion about shrews in Manitoba.

Shrews were captured in sagebrush-grass areas during 1979 only. In 1980 shrews were captured only in the riparian type. These observations support conclusions (Wrigley *et al.* 1979, Hoffman and Owen 1980) that several species are tolerant of different habitat conditions. Rodent populations on the study area were relatively higher in 1979 than in 1980. Intra- and interspecific competition for food and space with shrews and rodents may have had an effect on shrew distribution during 1979.

Wrigley *et al.* (1979) stated that vegetation type and cover were important to shrews through the maintenance of moisture levels in microhabitats. Our results show that wetter habitats support more shrews in southeastern Montana. Litter cover was greater in riparian and sagebrush-grass areas, where shrews were most abundant. Litter

cover helps to conserve soil moisture and provides a relatively moist microhabitat. The conservation of soil moisture provides more water for plant growth. As plants respire, relative humidity levels increase near the ground surface. The presence of vegetation reduces ground desiccation by disrupting air currents, blocking sun radiation, and stabilizing temperatures. Tree and shrub canopy is more effective at reducing desiccation than are shrubs alone. Plant species diversity may not be as important to shrews as the vegetative structure and litter type, as well as litter cover, provided by certain habitat types. Humidity levels in microhabitats may also play a role in shrew distribution.

Shrews were not captured in Sherman live traps during this study. The success of pitfall traps in capturing shrews may be related to the fact that insects become trapped in them. The occurrence of natural prey in pitfall traps makes these devices attractive foraging areas for shrews.

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# Mineral Content of Canada Goose Eggs and Implications for Environmental Surveillance Along the Columbia River

**Abstract**

Historically the main stem Columbia River has been relatively free from direct releases of man-induced mineral elements from industrial facilities. Eggs taken from deserted Canada goose nests from islands in the Hanford Reach of the Columbia River were chemically analyzed for an array of essential mineral nutrients as well as potentially toxic elements. These data provide new information concerning the mineral concentrations of soft parts of Canada goose eggs. Eggs are especially useful for environmental surveillance purposes because killing of birds is not required and eggs are available year after year. Mineral analyses are especially important at this time if changes in mineral concentrations in future years are to be detected following the addition of new industrial facilities along the Columbia that could introduce metals to terrestrial and aquatic ecosystems as airborne or liquid effluent releases.

## Introduction

Canada Geese, *Branta canadensis moffiti*, have maintained a small breeding population along the undammed Columbia River in southeastern Washington since the late 1940's (DeWaard 1981, Hanson and Eberhardt 1971) during an era when historical island nesting sites have steadily diminished with the construction of large hydroelectric dams on the Columbia and Snake Rivers (Gibson and Buss 1977, Ball *et al.* 1981). The Hanford Site, a 1400 $km^2$ area of mostly undeveloped sagebrush land, was established by the federal government in 1943 to provide an isolated location for the production and processing of plutonium. As a part of the Hanford site biological resource and wildlife surveillance programs, an annual census of goose nests on 20 riverine islands has been performed since 1953 (Rickard *et al.* 1982).

For 20 years plutonium production reactors located on the shore of the Columbia River used its water as a coolant. Heated water was returned to the river along with burdens of radioactive phosphorus, radioactive zinc and other radionuclides. Zinc-65 and $^{32}P$ was easily measured in the tissues of migrating ducks and geese that used the Hanford Reach of the Columbia River in autumn and winter (Hanson and Case 1963). Following the closure of eight of the production reactors in the 1970's, goose eggs from the Hanford Reach had low concentrations of radiocesium and radiostrontium derived from global fallout (Rickard and Sweany 1977). Zinc-65 and $^{32}P$ had disappeared due to river flushing and radioactive decay (Cushing *et al.* 1981).

The purpose of this article is to present data concerning stable (non-radioactive)

mineral element concentrations of goose eggs collected as available from deserted goose nests on islands in the Hanford Reach of the Columbia River on 15 April 1980, one month before the eruption of Mount St. Helens which deposited massive amounts of mineral rich tephra in a wide zone across eastern Washington and muddied the usually clear Columbia River in the Hanford Reach for more than a week.

### Methods

Eggs were taken from deserted goose nests on islands numbers 11, 12, 15, 17, and 19 in the Columbia River near Richland, Washington (Figure 1). The egg shells were removed and the inner contents freeze-dried preparatory to elemental analyses. The freeze-dried material was digested in a mixture of nitric and perchloric acid. Lead, copper, and chromium were determined by graphite furnace atomic absorption spectroscopy; selenium by hydride generation, sulfur by Leco induction furnace; and aluminum, calcium, iron, magnesium, manganese, nickel, phosphate, potassium, barium, strontium, sodium, and zinc by inductive coupled argon plasma spectroscopy. Results are expressed as parts per million dry weight.

### Results and Discussion

Phosphorus, sulfur, and sodium were the most abundant elements in goose eggs followed by calcium, potassium, and magnesium. Calcium concentrations were higher in eggs from certain clutches taken from islands 17 and 19 with values ranging from 4400-6600 ppm as compared to values ranging from 2200 to 4000 for upstream islands. This can probably be attributed to differences in embryo development stage because the elevated levels were associated with the most advanced embryo stages.

Eggs collected from island 17 had about the same levels of trace elements Cu, Zn, Mn, and Se as compared to eggs taken from islands 11, 12, 15, and 19 (Table 1). Eggs from two of three clutches from island 17 had enhanced levels of Al, Ni, and Cr but Pb levels were only marginally elevated (Table 1). One egg from a single clutch from island 19 also had enhanced levels of these same elements. Island 17 is located within one kilometer of a uranium fuel fabrication facility located on the western bank of the Columbia River (Figure 1) and island 19 is located several km downstream. Leaching ponds located near the western shore of the Columbia River have received liquid effluents and slurry generated during 40 years of fabrication of uranium fuel. These ponds may be the source of enhanced levels of Al, Ni, and Cr in Canada Goose eggs as these materials are abundantly used in fuel fabrication. It is also possible that these values are well within the normal range of mineral concentrations for goose eggs, but no published information for comparison purposes was found.

Goose nesting along the Hanford Reach begins in early March (Hanson and Eberhardt 1971). Nesting geese provide a natural population that can be used as an indicator of biologically available metal contamination in their foraging environment. In order for female geese to obtain body burdens of metals for transfer to eggs, a metal source needs to be present before and possibly throughout the spring egg-laying season. This source could be either green plants or soil particles externally attached to plants. It seems likely that nesting geese would not travel great distances in search of food if green forage plants were available near their nest islands. Green forage plants are available all along the shore of the Columbia River and also on the shorelines of the islands.

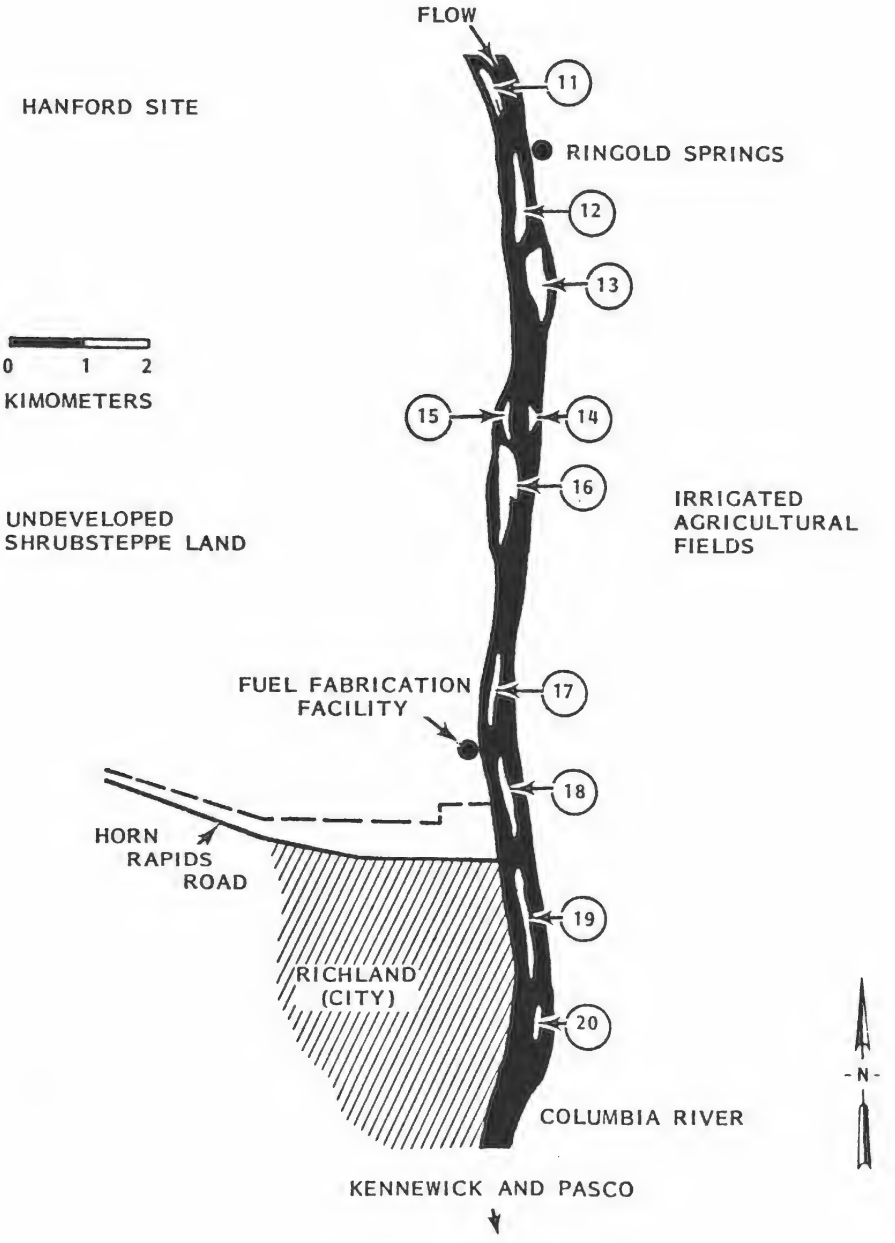


Figure 1. Map showing the Columbia River and goose nesting islands with identification numbers and the location of the fuel fabrication facility on the U.S. Department of Energy's Hanford Site.

TABLE 1. Range of mineral elements (ppm dry wt.) in Canada goose eggs collected from deserted nests on five island numbers 11, 12, 15, 17, and 19 on the Hanford Reach of the Columbia River arranged from upstream to downstream. Values under the lines are from the same clutch.

| | 11 | 12 | 15 | 17 | | | 19 |
|---|---|---|---|---|---|---|---|
| | 5 Eggs | 3 Eggs | 2 Eggs | 2 Eggs | 1 Egg | 1 Egg | 1 Egg |
| Se | 0.45-0.60 | 0.25-0.80 | 0.35-0.35 | 0.45-0.60 | 0.60 | 0.75 | 0.50 |
| Mn | 1.8-2.0 | 1.0-1.2 | 1.0-1.0 | 3.8-4.7 | 2.2 | 2.5 | 1.9 |
| Cu | 3.6-5.0 | 3.6-3.8 | 3.8-4.1 | 4.2-4.3 | 4.5 | 3.2 | 4.3 |
| Zn | 47-49 | 47-57 | 46-50 | 55-56 | 52 | 51 | 49 |
| Pb | 0.80-0.90 | 0.68-0.90 | 0.93-1.0 | 1.5-1.7 | 0.93 | 1.2 | 1.5 |
| Cr | 0.50-0.20 | <0.05-0.10 | <0.05-0.25 | 1.5-3.2 | 3.95 | 0.65 | 3.7 |
| Ni | <1.3 | <1.3 | <1.3 | 16-25 | 14 | <1.3 | 7.9 |
| Al | <8-15 | <8-10 | <8 | 43-118 | 58 | <8 | 294 |
| Fe | 99-115 | 85-107 | 92-103 | 156-156 | 140 | 116 | 106 |
| Sr | 1.7-2.5 | 3.9-4.4 | 2.6-2.8 | 4.8-5.1 | 3.4 | 3.1 | 4.9 |
| Ba | 3.9-7.8 | 5.8-6.6 | 5.6-6.6 | 4.8-7.1 | 8.0 | 6.2 | 9.1 |
| Ca | 2200-3300 | 2900-4100 | 3400-4000 | 4400-4800 | 4800 | 2300 | 6600 |
| Mg | 390-480 | 400-470 | 360-380 | 440-490 | 520 | 500 | 450 |
| $PO_4$ | 21000-23000 | 23000-24000 | 22000-23000 | 24000-25000 | 24000 | 21000 | 23000 |
| S | 5500-6800 | 4600-6100 | 5000-5400 | 4600-4600 | 7800 | 5300 | 5400 |
| K | 2900-3400 | 3600-4100 | 3100-3600 | 3500-3500 | 3800 | 3500 | 3500 |
| Na | 3800-4300 | 4000-4300 | 3600-3700 | 4400-4500 | 4200 | 4000 | 4100 |

Leakage from the retention ponds has reached the shoreline of the Columbia River but there are no measurements of mineral concentrations in shoreline vegetation as most of the environmental surveillance associated with the Hanford Site has been concerned with radionuclides rather than stable elements.

Historically the Hanford Reach of the Columbia River and its shoreline environment has been relatively free from industrially induced metals in comparison to streams in northern Idaho, for example, where mining and/or smelting has been practiced for a century or more. Fish scraps and feces collected from heron nests on the Hanford Reach showed relatively low amounts of Cd, Pb, and Hg as compared to heron debris collected at Lake Chatcolet in northern Idaho (Fitzner *et al.* 1982).

Most studies of waterfowl and mineral elements have been concerned with measurement of specific toxic elements in body tissues and determining the amount of material required to cause mortality (Alder 1944, Bellrose 1959, Chupp and Dalke 1964, Longcore *et al.* 1974, Stendell 1980).

Goose eggs taken from the Umatilla National Wildlife Refuge located downriver from the Hanford Reach had high levels of heptachlor (Blus *et al.* 1979). Heptachlor is used as an insecticide treatment for winter wheat prior to planting in the fall. These data show the potential for parent birds to transfer the organic chemical compounds to eggs and to embryos.

Our preliminary study relied on taking egg samples as available because we did not wish to impose additional mortality on a goose population that had declined from 300 nesting pairs in the early 1950's to about 150 nesting pairs in the 1980's (Ball *et al.* 1981).

Collecting eggs from abandoned goose nests is a practical way to monitor an important wildlife species for metals like mercury that can be passed from the parent birds to eggs (Stendell, 1977). Eggs are especially useful for surveillance purposes be-

cause birds of high esthetic and recreational value need not be killed to obtain samples suitable for chemical analyses, and eggs can be obtained year after year.

It is likely that in future years the Columbia Basin will receive inputs of trace elements from coal combustion plants producing electricity for a growing population and that various agricultural chemicals will be employed to sustain crop production. The only way to determine whether or not these environmental pollutants affect wildlife populations is to conduct environmental surveillance programs that include wildlife sampling and appropriate chemical measurements.

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# Ectoparasitic Mites (Excluding Chiggers), Fleas, and Lice from Pocket Gophers, Thomomys, in Oregon

## Abstract

Four of the five species of pocket gophers that occur in Oregon were examined for ectoparasites; these included: (1) Camas pocket gopher, *Thomomys bulbivorus*, (2) Townsend pocket goprer, *T. townsendi*, (3) Mazama pocket gopher, *T. mazama*, and (4) northern pocket gopher, *T. talpoides*. Although the Botta pocket gopher, *T. bottae*, occurs in southwestern Oregon, none was included in this study.

Major ectoparasites were *Androlaelaps geomys* and *Geomydoecus oregonus* on *T. bulbivorus; Echinonyssus thomomys, Haemogamasus onychomydis,* and *Geomydoecus idahoensis* on *T. townsendi; Haemogamasus reidi, Geomydoecus thomomys; Androlaelaps geomys,* and *Foxella ignota recula* on *T. mazama; Geomydoecus thomomys, Echinonyssus thomomys, Echinonyssus longichelae* (?), and *Foxella ignota recula* on *T. talpoides.*

## Introduction

Five species of pocket gophers occur in Oregon, all in the genus *Thomomys*; they include the Camas pocket gopher, *T. bulbivorus*, Townsend pocket gopher, *T. townsendi* (listed as *T. umbrinus* by Hall 1981), Mazama pocket gopher, *T. mazama*, northern pocket gopher, *T. talpoides*, and Botta pocket gopher, *T. bottae.* The latter is not included in this study. Pocket gophers are unusual among North American rodents in that they harbor chewing lice, Mallophaga, rather than sucking lice, Anoplura. Chewing lice are exceedingly host-specific; those of pocket gophers are in the genus *Geomydoecus. Geomydoecus oregonus* occurs on *T. bulbivorus, G. idahoensis* on *T. townsendi,* and *G. thomomys* on both *T. mazama* and *T. talpoides* (Price and Emerson 1971, Price and Hellenthal 1980).

Mites reported from *T. bulbivorus* are *Androlaelaps fahrenholzi* and *A. geomys.* Those reported from *T. talpoides* are *Androlaelaps fahrenholzi, A. geomys, Eulaelaps*

*stabularis, Haemogamasus ambulans, H. longitarsus, H. occidentalis, H. onychomydis, H. reidi, Echinonyssus femuralis, E. geomydis, E. isabellinus, E. longichelae, E. neotomae, E. thomomys, E. utahensis*, and *Hypoaspis miles* (Whitaker and Wilson 1974). There apparently are no previously reported parasitic mites on *T. mazama* and *T. townsendi.* Pocket gophers of the various genera and species are host to 19 species of fleas, which are currently assigned to three genera.

This paper presents information on the latter parasitic mites, chewing lice, and fleas, of pocket gophers in Oregon. Although gophers, *Thomomys,* spend more time above ground than do gophers of other genera, pocket gophers are generally isolated from other animals and from other species of gophers. Such isolation gives us the opportunity to examine communities of parasites from four closely related species of pocket gophers from a relatively limited area, as well as to provide new data on ectoparasitic mites from two species of gophers.

#### Study Area

The five species of pocket gophers that occur in Oregon do not, so far as is known, overlap (Bailey 1936, Hall 1981, Maser *et al.* 1981) but follow the physiographic provinces of Oregon as defined by Franklin and Dyrness (1973). For example, the southern pocket gopher occurs mainly in the Umpqua and Rogue Valleys and in the extreme southern extension of the Sitka spruce (*Picea sitchensis*) zone of the Klamath Mountains province. The Camas pocket gopher is endemic to the Willamette Valley within the Willamette Valley province. The Mazama pocket gopher inhabits meadow areas of the Coast Ranges, Western Cascades, and High Cascades Provinces, regardless of major vegetation type. In fact, one small, isolated population just penetrates the Klamath Mountains province at Pistol River, Curry County. Two species occur east of the High Cascades Province. The most widely spread is the northern pocket gopher that occurs in all major vegetation types within the following four provinces: Basin and Range, High Lava Plains, Blue Mountains, and Owyhee Upland. The Townsend pocket gopher occupies two limited areas of the Shrub-Steppe (with bit sagebrush, *Artemisia tridentata*) and Desert Shrub major vegetation types within the Basin and Range and Owyhee Upland Provinces. Where the northern and Townsend pocket gophers would appear to be sympatric, they are separated by soil type—the Townsend pocket gopher inhabits deep well-drained soils whereas the northern pocket gopher inhabits shallow, stony soils (Maser, unpublished data).

#### Methods and Materials

Pocket gophers were trapped, placed in plastic bags, and quick-frozen in the field with dry ice (Maser *et al.* 1978). After they were transported to the laboratory and thawed, standard museum data were taken. They were then examined for mites and fleas by brushing their fur over a white porcelain pan; this method of collection selects for larger specimens and misses many of the smaller forms. More detailed examinations will show small mites, particularly *Geomylichus* sp. (Listrophoridae), to be abundant (Fain *et al.* 1978). The fur was examined visually for lice, which were individually collected with the aid of forceps. Parasites were preserved in 70 percent ethyl alcohol, cleared in Nesbitt's, and mounted in Hoyer's solution. Pocket gopher sample sizes were: 8 for *T. bulbivorus*, 11 for *T. townsendi*, 27 for *T. mazama*, and 106 for *T. talpoides.*

## Results

Information on ectoparasites of the four species of pocket gophers is given in Table 1.

The hosts, with their most numerous parasites listed in order of decreasing abundance, were (1) *T. bulbivorus—Androlaelaps geomys* and *Geomydoecus oregonus,* (2) *T. townsendi—Echinonyssus thomomys,* (3) *T. mazama—Foxella ignota recula, Geomydoecus thomomys, Haemogamasus reidi,* and *Androlaelaps geomys,* and (4) *T. talpoides—Foxella ignota recula, Geomydoecus thomomys, Echinonyssus thomomys,* and *E. longichelae.*

The louse, *Geomydoecus oregonus,* was found on *T. bulbivorus,* and *G. idahoensis* was found on *T. townsendi. Geomydoecus thomomys* occurred on both *T. mazama* and *T. talpoides.*

*Androlaelaps geomys* is generally a common mite on pocket gophers. It was the most abundant ectoparasite on *T. bulbivorus,* fourth in abundance on *T. mazama,* but not even found on *T. townsendi* or *T. talpoides.*

More than one type of mite keyed out to *Echinonyssus longichelae*; differences occurred in the spur of coxa II of the female. In typical *E. longichelae,* this spur was found to be about 8$\mu$ m long by 7$\mu$ m wide. The individuals we listed as *E. longichelae* variant, however, had a much larger spur on coxa II; it was about 24$\mu$ m long and 17$\mu$ m wide in mites from *T. mazama* and about 18$\mu$ m long and 16$\mu$ m wide in those from *T. talpoides.* Dr. C. S. Herrin examined specimens from *T. mazama* and referred to them either as a variant of *Echinonyssus longichelae* or as a new species. There is also a problem with *Echinonyssus thomomys* in that mites from *T. talpoides* have setae on the dorsal plate that are all approximately the same length (about 30 mm), but individuals from *T. mazama* have much shorter setae, more like those in *Echinonyssus geomydis* of *E. femuralis.* A comparative study of *Echinonyssus* from these gophers is needed.

We found three taxa of fleas on gophers, *Foxella ignota recula* and *Spicata comis comis* on *T. mazama* and both of these plus *Foxella ignota utahensis* on *T. talpoides.* No fleas were found on *T. bulbivorus* or *T. townsendi* (Table 1).

The flea, *Spicata comis comis,* was grouped, until recently, with 14 allied taxa in the genus *Dactylopsylla.* Members of the genus *Spicata,* also specific to pocket gophers, are rarely collected in large numbers. They are rare in collections, which leads us to suspect that they are nest fleas that peak in population during winter when the host cannot be easily collected. The genus *Spicata* is badly in need of taxonomic revision, but lack of sufficient numbers of specimens has delayed such a study. The specimens we report here (Table 1) were taken from March through September.

## Discussion

The major parasites of pocket gophers in Oregon include: fleas *Foxella* (*ignota*); chewing lice, *Geomydoecus,* (*oregonus, idahoensis, thomomys*); and mites, *Androlaelaps* (*geomys*), *Haemogamasus* (*reidi, onychomydis, thomomys*), and *Echinonyssus* (*femuralis, longichelae, thomomys*). Although there is much similarity between the major ectoparasites of gopher species, there are also some interesting differences. No specimens of *Androlaelaps* were found on *T. townsendi* or *T. talpoides.* Fleas and *Haemogamasus reidi* were found on *T. mazama* and *T. talpoides,* but not on the other two gophers. *Haemogamasus onychomydis* was common only on *T. townsendi.*

The flea complex, *Foxella ignota,* contains 11 currently recognized subspecies that

TABLE 1. Fleas, chewing lice, and mites from the fur of four species of pocket gophers, **Thomomys**, in Oregon.

| | **bulbivorus** | | | | **mazama** | | | | **talpoides** | | | | **townsendi** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. examined | 8 | | | | 27 | | | | 106 | | | | 11 | | | |
| | Number | | Occurrence | | Number | | Occurrence | | Number | | Occurrence | | Number | | Occurrence | |
| | Total | Av. | No. | % | Total | Av. | No. | % | Total | Av. | No. | % | Total | Av. | No. | % |
| Siphonaptera | | | | | | | | | | | | | | | | |
| **Foxella ignota recula** | | | | | 119 | 4.40 | 26 | 96.3 | 170 | 1.60 | 31 | 29.2 | | | | |
| **Foxella ignota utahensis** | | | | | | | | | 19 | 0.20 | 8 | 7.5 | | | | |
| **Spicata comis comis** | | | | | 12 | 0.40 | 10 | 37.0 | 3 | 0.02 | 3 | 2.8 | | | | |
| Mallophaga | | | | | | | | | | | | | | | | |
| **Geomydoecus thomomys** | | | | | 64 | 2.40 | | 29.6 | 121 | 1.1 | 13 | 12.3 | | | | |
| **G. oregonus** | 24 | 3.0 | 5 | 62.5 | | | | | | | | | | | | |
| **G. idahoensis** | | | | | | | | | | | | | 3 | 0.3 | 2 | 18.2 |
| Acarina | | | | | | | | | | | | | | | | |
| Laelapidae | | | | | | | | | | | | | | | | |
| **Androlaelaps geomys** | 86 | 10.8 | 5 | 62.5 | 47 | 1.70 | 5 | 18.5 | | | | | | | | |
| **Haemogamasus onychomydis** | | | | | 1 | 0.04 | 1 | 3.7 | 3 | 0.03 | 2 | 1.9 | 6 | 0.5 | 3 | 27.3 |
| **H. reldi** | | | | | 66 | 2.40 | 3 | 11.1 | 8 | 0.08 | 5 | 4.7 | | | | |
| **H. thomomysis** | | | | | 3 | 0.10 | 2 | 7.4 | 1 | 0.01 | 1 | 0.9 | | | | |
| **Echinonyssus femuralis** | 3 | 0.4 | 1 | 12.5 | | | | | 1 | 0.01 | 1 | 0.9 | | | | |
| **E. longichelae** | | | | | 3 | 0.10 | 1 | 3.7 | 4 | 0.04 | 2 | 1.9 | | | | |
| **E. longichelae** variant no. 1 | | | | | 4 | 0.15 | 2 | 7.4 | 34 | 0.32 | 8 | 7.5 | | | | |
| **E. thomomys** | | | | | 21 | 0.80 | 2 | 7.4 | 39 | 0.37 | 11 | 10.4 | 19 | 1.7 | 2 | 18.2 |
| **E. utahensis** | | | | | | | | | 1 | 0.01 | 1 | 0.9 | | | | |
| **Laelaps alaskensis** | | | | | 1 | 0.04 | 1 | 3.7 | | | | | | | | |
| Ascidae | | | | | | | | | | | | | | | | |
| **Proctolaelaps** sp. | | | | | | | | | 3 | 0.03 | 3 | 2.8 | | | | |
| Macrochelidae | | | | | | | | | | | | | | | | |
| **Macrocheles** sp. | | | | | | | | | 2 | 0.02 | 2 | 1.9 | 1 | 0.1 | 1 | 9.1 |
| Glycyphagidae | | | | | | | | | | | | | | | | |
| **Glycyphagus hypudaei** | | | | | 1 | 0.04 | 1 | 3.7 | | | | | | | | |
| Histiostomatidae | | | | | 1 | 0.04 | 1 | 3.7 | | | | | | | | |

occur on pocket gophers throughout the western two-thirds of the United States and southern Canada. The species has not been reported east of Indiana where the nominate subspecies occurs, and the western complex of taxa is poorly understood and in need of taxonomic revision. *Foxella ignota recula* has a broad distribution in the Pacific Northwest, from Idaho west to the coast and from northern Nevada and California to southern British Columbia; it occurs on the various species of pocket gophers, as well as on other species of mammals that frequent the gopher burrows.

The occurrence of *Foxella ignota utahensis* in Oregon was unexpected. The taxon had been previously reported from Utah and Idaho (Hubbard 1947). We collected it in Harney, Malheur, and Union Counties, all in eastern Oregon. The subspecies, *utahensis,* seems to be restricted to more arid regions and was only collected with the subspecies, *recula*, in Malheur County.

Major parasites of the plains pocket gopher, *Geomys bursarius*, in Indiana include a chewing louse, *Geomydoecus illinoiensis*; a flea, *Foxella ignota*; and mites, *Androlaelaps geomys, Echinonyssus longichelae, E. geomydis,* and *Geomylichus floridanus* (Tuszynski and Whitaker 1971). Likewise, in Colorado where there are four species of gophers representing three genera, major parasites were chewing lice, *Geomydoecus* (six species), a flea, *Foxella ignota*, and the mites, *Androlaelaps, Geomys, Haemogamasus "ambulans"* (probably *H. reidi*), and *Echinonyssus geomydis.* The latter two mites were abundant only on one species of gopher (Miller and Ward 1960).

Although there are great similarities among the parasites of pocket gophers from the three areas, there are also some differences. The similarities included a complex of chewing lice, *Geomydoecus* spp.; the flea, *Foxella ignota*; and the mites, *Androlaelaps geomys, Haemogamasus* sp., and *Enchinonyssus* sp. The major differences were: (1) an apparent lack of listrophorid mites in Colorado and Oregon, but an abundance in Indiana, and (2) fewer *Haemogamasus* sp. on gophers in the east (Indiana) and a reduced incidence of *Echinonyssus* sp. in the community of ectoparasites on gophers in Colorado.

The apparent lack of listrophorid mites in Colorado and Oregon may be an artifact of collecting, however, and not a real difference. As noted earlier, these mites are tiny and cling to individual hairs, so are regularly overlooked during routine searches for ectoparasites. We suspect that listrophorids may be abundant on gophers of both Colorado and Oregon. In support of this, we have recently examined a series of pocket gophers, *Thomomys,* from California and found a listrophorid, *Geomylichus* sp., to be abundant there.

Only one species of *Echinonyssus* was found in Colorado, and it was abundant on only one species of gopher (Miller and Ward 1960). In Indiana, two species were involved (Tuszynski and Whitaker 1971), *E. longichelae* with large, rounded coxal spurs, and *E. geomydis* with smaller, pointed coxal spurs. In Oregon, two species were found on *T. mazama* and *T. talpoides, E. longichelae* and *E. thomomys*, the latter again with smaller pointed coxal spurs. Only *E. thomomys* was found on *T. townsendi*, and only *E. femuralis* was found on *T. bulbivorus.* It does seem peculiar the *Echinonyssus* was not more prominent on gophers from Colorado.

Many species of chewing lice inhabit birds. Chewing lice that inhabit North American mammals are primarily parasites of carnivores and ungulates. Two native rodent families (gophers, Geomyidae, and porcupines, Erethizontidae), and Guinea pigs, *Cavia* sp., and nutrias, *Myocastor coypus,* also serve as hosts. The chewing lice of pocket

gophers, *Geomydoecus*, are highly host specific. In Oregon, for example, *Geomydoecus thomomys* occurs on both *T. mazama* and *T. talpoides*, which suggests that they are closely related on sibling species. The geographical distribution of these two species of pocket gophers is parapatric (Hall 1981), as one would expect of a single species. Differences in their bacula, however, are much greater than would be expected in members of the same species (Johnson and Benson 1960), as are differences in their habitats (Bailey 1936). In addition, *Geomydoecus oregonus* is specific to *T. bulbivorus*, a narrowly endemic species, and *Geomydoecus idahoensis* is specific to *T. townsendi* (Price and Hellentha 1980). *Thomomys bottae* (= *umbrinus*) (Hall 1981) has *Geomydoecus shastensis* as a host-specific louse (Price and Hellenthal 1980), and *T. bottae*, confined to southwestern Oregon, is geographically isolated from other species of pocket gophers in the state. Clearly much evolutionary radiation has occurred in the chewing lice of gophers. Each host species has at least one, and often two species of chewing louse (Emerson 1972).

The host-parasite relationships between the host-specific lice, *Geomydoecus*, is inconsistent with Hall's (1981) treatment of *T. umbrinus* but supports the taxonomic treatment of Patton and Smith (1981). A detailed taxonomic study of *Geomydoecus* may help clarify the taxonomic relationship of *Thomomys*.

Pocket gophers are relatively isolated from other species. This is well illustrated by their ectoparasites, most of which are restricted, or nearly restricted, to pocket gophers. Among the ectoparasites of pocket gophers of Oregon, all the fleas and lice, and most of the more abundant mites, *A. geomys* and mites of the genus *Echinonyssus*, are so restricted. *Haemogamasus reidi* was the only abundant ectoparasite not essentially restricted to pocket gophers. It is generally found on squirrels.

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# Effects of Volcanic Ash on Food Habits of Burrowing Owls at Moses Lake, Washington

## Abstract

Prey items from 200 Burrowing Owl (*Speotyte cunicularia*) pellets collected near Moses Lake, Washington, were identified and compared between the summer immediately following ash deposits from the 1980 Mount St. Helens eruption and the summer of 1981. During 1980, insects comprised 94 percent of prey items and 6 percent were mammalian. Insect prey decreased to 68 percent in 1981 and mammalian prey increased to 32 percent.

## Introduction

On 18 May 1980 a plume of volcanic ash from the eruption of Mount St. Helens passed over central Washington state depositing approximately 5 cm of fine ash near Moses Lake (Korosec *et al.* 1980). The rain that fell shortly afterward compacted much of the ash into a crust on the soil surface. Detailed descriptions and environmental impacts of the volcanic ash are reported by Fruchter *et al.* (1980) and Cook *et al.* (1981). The primary objective of this study was to determine the impact of ash deposition on food habits of burrowing owls.

## Study Area and Methods

The study area was located in central Grant County and western Adams County, Washington. Owl pellets were collected at numerous active nest burrows immediately adjacent to Interstate 90 between Moses Lake and George and adjacent to State Route 17 between Moses Lake and Othello. Interstate 90, with its accompanying frontage roads, and State Route 17 are the major roads located on the study area. Farm crops are grains, potatoes, alfalfa, and hay pastures. The road right-of-ways and irrigation canal banks, which provide much of the available habitat for nest burrows, have been planted to various grass species, mainly crested wheatgrass (*Agropyron critatum*), tall wheatgrass (*A. elongatum*) and Sherman's bluegrass (*Poa ampla*). Most nest burrows appear to be modified badger (*Taxidea taxus*) holes, although some small road culverts were also utilized.

Native plant communities have been severely affected by development of trans-

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portation corridors and irrigated agriculture. Remaining vegetation is dominated by cheatgrass (*Bromus tectorum*) and grey rabbitbrush (*Chrysothamnus nauseosus*). Although, some remnant patches of bigsage (*Artemisia tridentata*)/bluebunch wheatgrass (*A. spicatum*), big sage/Sandberg's bluegrass (*P. secunda*) and bitterbrush (*Purslia tridentata*)/needlegrass (*Stipa comata*) communities are scattered through the study area. The largest block of native vegetation is located west of Moses Lake and south of Interstate 90 within the Washington Game Department's Potholes Habitat Management Area.

The topography is basically a flat prairie but is dissected occasionally by shallow coulees. Soils are very sandy west of Moses Lake and loamy south into the Othello area. Mean annual precipitation is 20 cm, occurring mostly in winter as snow. Temperatures range from -28 C to 43 C.

Regurgitated burrowing owl pellets were collected weekly from burrows during June-August 1980 and June-August 1981. A total of 200 pellets were dissected and contents identified—100 from 1980 and 100 from 1981. Analysis of pellets generally followed methods of Errington (1930) and Marti (1974). Mammalian prey were identified and counted by examining skulls and dentaries. The insect prey were identified and counted with whole heads and mandibles. Other body parts such as legs and elytra were too fragmented to identify or count accurately. A chi-square contingency table was used to compare food habits between 1980 and 1981.

#### Results and Discussion

Insects comprised the majority of prey of burrowing owls at Moses Lake, Washington, during the summer of 1980 and 1981 (Table 1). In 1980, 94 percent of the prey were insects and 6 percent were mammalian. Insects decreased to 68 percent of the prey in

TABLE 1. Comparison of Burrowing Owl prey immediately following the Mount St. Helens eruption (1980) with prey captured one year later (1981) at Moses Lake, Washington. Data from analysis of 100 pellets each year.

| | 1980 | | 1981 | |
|---|---|---|---|---|
| Prey | n | % | n | % |
| Insects | | | | |
| Coleoptera | | | | |
| Carabidae | 235 | 31 | 29 | 10 |
| Tenerionidae | 168 | 22 | 29 | 23 |
| Silphidae | 23 | 3 | 5 | 2 |
| Staphylinidae | 2 | tr* | — | — |
| Curculionidae | 13 | 2 | — | — |
| Unknown | 73 | 10 | 77 | 26 |
| Hymenoptera | | | | |
| Formicidae | 64 | 9 | 2 | tr |
| Orthoptera | | | | |
| Acrididae | 118 | 16 | 4 | 1 |
| Gryllacrididae | 6 | tr | 16 | 5 |
| Lepidoptera | 3 | tr | — | — |
| Mammals | | | | |
| **Peromyscus maniculatus** | 14 | 2 | 16 | 5 |
| **Perognathus parvus** | 10 | 1 | 49 | 16 |
| **Thomomys talpoides** | 3 | tr | 4 | 1 |
| **Microtus** spp. | 17 | 2 | 26 | 9 |
| **Mus musculus** | 3 | tr | 1 | tr |

*tr=trace, less than 1 percent.

1981 while mammals comprised 32 percent. Beetles (Coleoptera) were the most commonly obtained insects especially those of the families Carabidae (31 percent of the total prey in 1980 and 10 percent in 1981) and Tenebrionidae (22 percent of the prey in 1980 and 24 percent in 1981). Mammals were important to the owls in 1981, particularly the Great Basin pocket mouse (*Perognathus parvus*) which comprised 16 percent of the prey. By comparison, in 1980 pocket mice comprised only 1 percent of the prey. Ants (Formicidae) were a common prey in 1980. Longhurst (1942) suggested that ants were ingested accidentally as they clung to other food items. This does not appear to be true in this case because ants rarely occurred individually but were represented in large numbers in single pellets. They may have been accidentally ingested, however, by owls eating ant-infested carrion or cached prey.

Insects were the most numerous prey eaten, but individuals contributed little to the biomass of the diet. One pellet contained 27 beetles while only 4 mice comprised a similar sized pellet. Grasshoppers and crickets (Orthoptera) have a larger biomass than beetles; one pellet contained approximately 10 grasshoppers.

Burrowing owls have been observed foraging along the ground (Marti 1974, Martin 1973, Thomsen 1971) and this behavior may account for the large number of insects in the diet. The owls are also opportunistic feeders and will become more dependent upon vertebrates when insect availability decreases (Marti 1974). Insects are usually more abundant and easier to capture than vertebrates. Errington (1935) suggested that older owls more commonly captured vertebrates, and that prey capture skills of younger owls were more limited to slow-moving insects.

Although pellet analysis methods for determining raptor food habits have been reported as fairly accurate, especially in small-sized owls (Errington 1930, Glading *et al.* 1943), some prey may have been overlooked or misidentified if remains were highly fragmented. Soft-bodied insects and carrion may not have been represented in the analysis of pellets. Pellets that are comprised entirely of insects have been reported to disintegrate upon drying (Marti 1974, Coulombe 1971). Thus, proportionally more mammalian pellets may have been collected, especially if a violent wind and/or rain storm occurred between collection periods. We have no reason to suspect these potential biases seriously affect our data.

A chi-square contingency table test revealed a significant difference between prey capture in 1980 vs 1981 ($P < 0.05$). Insects comprised a much larger proportion of the diet in the summer of 1980 than 1981. A number of factors could be responsible for this difference: 1) Many insect populations suffered dramatic mortality from the volcanic ash (Akre *et al.* 1981, Brown and Hussain 1981, Shanks and Chase 1981). Large numbers of insects were reported lying on top of the ash layer in several affected regions (R. D. Akre, personal communication). Owls may have foraged along the ground, easily picking up the dead or dying insects. Since burrowing owls are opportunistic feeders and the insect prey was easily obtainable, few mammal prey were needed or sought; 2) The ash may have covered the ground and vegetation enough to make the insects more visible to the owls, creating easy foraging; and 3) The ash may have been detrimental to the mammals by fouling the respiratory tract or by abrasion to the eyes. Alopecia (hair loss) and palpebral (eyelid) swelling has been documented for *Peromyscus maniculatus* and *Microtus montanus* (Pyke 1984, in press). Small mammals may also have suffered from loss of food or other resources (Anderson 1982). Other un-

known factors may have caused mortality or behavioral changes that reduced availability of mammals to owls.

Our 1980 data were collected during a period of extreme environmental perturbation. The proportional representation of insects *vs* mammals, by our 1981 data set suggests that the presence of volcanic ash in 1980 may have caused a shift in food habits during this period (i.e., more insects and fewer mammals). However, our data sets from 1980 and 1981 are both within the general limits of previously published food habits data (Table 2). Consequently, ash from the 1980 Mount St. Helens eruption may have altered

TABLE 2. Comparison of the proportion of insects and mammals among selected[a] burrowing owl food habits studies.

| Source | Percent insects | Percent mammals | Location |
|---|---|---|---|
| This study—1980[b] | 93 | 5 | Washington |
| This study—1981[c] | 67 | 31 | Washington |
| Maser et al. 1971[d] | 65 | 32 | Oregon |
| Smith and Murphy 1973 | 87 | 11 | Utah |
| Marti 1974[d] | 91 | 8 | Colorado |
| Gleason and Craig 1979 | 79 | 8 | Idaho |
| Fitzner et al. 1980 | 76 | 17 | Washington |

[a]Includes only studies with directly comparable analyses.

[b]Data collected immediately following the eruption of Mount St. Helens; study area had approximately 5 cm of vocanic ash.

[c]Data collected one year after the eruption of Mount St. Helens.

[d]Summer data only.

the diet of Moses Lake burrowing owls, but our data do not indicate unusual stress due to prey availability or composition during this period.

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# Densities and Nesting Heights of Breeding Birds in an Idaho Douglas-Fir Forest

## Abstract

Population densities and nesting heights of breeding birds are described for an unlogged Douglas-fir forest in west-central Idaho. Bird populations were determined using spot-mapping techniques on six 8.1 ha plots from mid-May to late July, 1976 through 1979. Nests were located incidental to bird censuses and by additional day long searches. Bird populations ranged from 192 to 252 breeding pairs per 40 ha; 18 to 21 species were territorial. Standing crop biomass ranged from 189 to 237 g/ha. Also summarized are heights, substrates, and placement of 204 nests, representing 25 species. The most important nesting height strata in the Douglas-fir forest were the understory layer, with over 40 percent of the breeding bird population, and the overstory layer, with about 30 percent of the population. The ground, shrub, and midstory layers each accounted for about a tenth of the total nesting avifauna. Densities and other features of the breeding bird community are compared with data from Douglas-fir forests elsewhere in North America.

## Introduction

The interior Douglas-fir forest cover type, characterized by the Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), occurs in most of the western mountain ranges east of the Coast Range in British Columbia and east of the Cascades and Sierra Nevada in the United States (Ryker and Steele 1980). It is widely distributed in eastern Washington and Oregon, Idaho, Montana, Wyoming, Utah, Colorado, Arizona, and New Mexico. The type is found at elevations from 370 to 2440 m in the northern Rockies, from 1830 to 2590 m in the central Rockies, and from 2440 to 2900 m in the southwest.

In west-central Idaho, Douglas-fir is a seral species on moist sites and is gradually replaced by grand fir (*Abies grandis*) and western hemlock (*Tsuga heterophylla*). On drier sites it persists and eventually forms pure climax stands; here western larch (*Larix occidentalis*) and ponderosa pine (*Pinus ponderosa*) may aggressively invade disturbed sites and temporarily relegate Douglas-fir to a less prominent position in young stands.

Despite Douglas-fir forests' distribution and economic, recreational, and esthetic values (Garrison *et al.* 1977), relatively little quantitative information has been published on bird populations of this important forest cover type. This paper describes densities, nesting heights, and other features of the breeding birds of a Douglas-fir forest in west-central Idaho.

## Study Area and Methods

This study was conducted on six small, unlogged watersheds (Silver Creek Experimental Area) of the Boise National Forest in the headwaters of the Silver Creek drainage, a tributary to the Middle Fork of the Payette River. The area is about 90 km northeast

of Boise in Valley County, Idaho. The watersheds range from 26 to 202 ha in size and from 1375 to 2040 m in elevation. Slope gradients vary from the nearly level lower slopes to the steep and dissected upper slopes. Most drainages flow in a southeasterly direction.

Douglas-fir and ponderosa pine are the dominant overstory trees, with scattered stands of grand fir, lodgepole pine (*Pinus contorta*), and Engelmann spruce (*Picea engelmannii*). Ninebark (*Physocarpus malvaceus*) and white spiraea (*Spiraea betulifolia*) normally dominate the shrubby undergrowth, but willow (*Salix* spp.), mountain maple (*Acer glabrum*), snowberry (*Symphoricarpos* spp.), and huckleberry (*Vaccinium globulare*) are often present. Numerous forbs and graminoids occupy the ground layer. Douglas-fir/ninebark and Douglas-fir/white spiraea are the main habitat types represented (Steele *et al.* 1981).

Six 8.1 ha plots, one located in each experimental watershed, were censused for breeding birds using the Williams spot-map method (International Bird Census Committee 1970). Methodological difficulties and other special problems of the mapping method are summarized by Oelke (1981) and Dawson (1981). Plots were chosen for uniformity and varied in shape from square to rectangular depending on terrain. Plots were surveyed and gridded in a Cartesian coordinate system with points flagged and numbered with steel stakes at 50 m intervals. At least 10 census visits were made to each plot from mid-May to late July from 1976 through 1979. Most of the work was done from sunrise to late morning when birds were most active. To ensure complete coverage, the plot was censused by walking within 25 m of all points on the grid. Observations extended well beyond plot boundaries.

At the end of the sampling period, concentrated groups of observations were circled as indicating areas of activity or approximate territories. Fractional parts of boundary territories were recognized. Results were converted to the number of pairs breeding birds per 40 ha. Shannon's formula, $H' = -\Sigma p_i \ln p_i$, where $p_i = N_i/N$ is the proportion of the collection belonging to the $i$th species, was used to calculate the species diversity index (Shannon and Weaver 1963). Bird nests were located incidental to bird censuses and by additional daylong searches. Nest heights above the ground were measured directly for lower nests and by use of a steel measuring tape and Abney level for the higher nests. Nest substrate, nest placement, plant species, nest tree diameter and height, and other information about nest-site location were also recorded.

#### Results and Discussion

##### Nest Heights

Table 1 summarizes heights, substrates, and placement of 204 nests, representing 25 taxa. Only 1 nest was found for 5 species; 5 or more nests were found for 14 species. Nests of the *Empidonax* flycatchers, for which specific identification could not be confirmed, were grouped.

Nest heights ranged from ground level to nearly 40 m above the ground. Within this range, 31 nests (15 percent) were on or near the ground (less than 0.5 m), 57 nests (28 percent) were in the shrub layer (0.5 to 3 m), 31 nests (15 percent) were in the understory layer (3 to 6 m), 40 nests (20 percent) were in the midstory layer (6 to 12 m), and 45 nests (22 percent) were in the overstory layer of the forest (over 12 m). Over half the nests found (58 percent) were in the ground, shrub, and under-

TABLE 1. Nest height, nest substrate, and nest placement of 25 species of birds.

| Species | Sample size | Nest height (m) $\bar{x}$ | Nest height (m) range | Nest substrate | Nest placement |
|---|---|---|---|---|---|
| Calliope Hummingbird (**Stellula calliope**) | 2 | 5.0 | 0.9-9.1 | Coniferous tree, deciduous shrub | Horizontal branch |
| Northern Flicker (**Colaptes auratus**) | 7 | 18.3 | 1.5-39.6 | Dead, live coniferous tree | Trunk, branch cavity |
| Hairy Woodpecker (**Picoides villosus**) | 12 | 6.6 | 1.8-16.8 | Dead, live coniferous tree | Trunk, branch cavity |
| Black-backed Woodpecker (**Picoides arcticus**) | 2 | 1.2 | 0.6-1.8 | Live coniferous tree | Trunk cavity |
| Flycatcher (**Empidonax** spp.)[a] | 17 | 5.6 | 0.6-15.5 | Coniferous tree, deciduous and evergreen shrub | Horizontal branch, upright crotch |
| Olive-sided Flycatcher (**Contopus borealis**) | 5 | 14.8 | 9.1-19.8 | Coniferous tree | Horizontal branch |
| Mountain Chickadee (**Parus gambeli**) | 12 | 16.8 | 3.0-39.0 | Dead, live coniferous tree | Trunk, branch cavity |
| White-breasted Nuthatch (**Sitta carolinensis**) | 1 | 3.4 | — | Live coniferous tree | Trunk cavity |
| Red-breasted Nuthatch (**Sitta canadensis**) | 14 | 16.3 | 2.7-32.0 | Dead, live coniferous tree | Trunk cavity |
| Brown Creeper (**Certhia americana**) | 6 | 5.6 | 0.6-11.0 | Dead, live coniferous tree | Between bark and trunk |
| Winter Wren (**Troglodytes troglodytes**) | 1 | 0.3 | — | Deciduous sapling | Exposed root mass |
| American Robin (**Turdus migratorius**) | 20 | 4.7 | 1.2-12.5 | Coniferous tree, deciduous sapling | Fork, horizontal branch |
| Hermit Thrush (**Catharus guttatus**) | 1 | 2.7 | — | Coniferous tree | Fork, horizontal branch |
| Swainson's Thrush (**Catharus ustulatus**) | 18 | 3.2 | 0.9-9.8 | Coniferous tree, deciduous sapling | Fork, horizontal branch |
| Townsend's Solitaire (**Myadestes townsendi**) | 2 | 0.7 | 0.4-0.9 | Ground, stump | Stump, cavity, tangled twigs of dead tree |
| Ruby-crowned Kinglet (**Regulus calendula**) | 5 | 7.5 | 4.0-10.4 | Coniferous tree | Horizontal branch, thick foliage |
| Solitary Vireo (**Vireo solitarius**) | 4 | 5.7 | 1.8-9.1 | Coniferous tree | Horizontal branch, semipensile |
| Nashville Warbler (**Vermivora ruficapilla**) | 1 | 0. | — | Ground | Litter, beneath evergreen shrub |
| Yellow-rumped Warbler (**Dendroica coronata**) | 3 | 8.4 | 7.6-9.1 | Coniferous tree | Horizontal branch |
| Townsend's Warbler (**Dendroica townsendi**) | 1 | 5.8 | — | Coniferous tree | Horizontal branch |
| MacGillivray's Warbler (**Oporornis tolmiei**) | 10 | 0.5 | 0.2-0.9 | Deciduous shrub | Upright crotch |
| Western Tanager (**Piranga ludoviciana**) | 13 | 12.3 | 2.4-16.8 | Coniferous tree | Horizontal branch |
| Cassin's Finch (**Carpodacus cassinii**) | 3 | 14.2 | 10.4-20.7 | Coniferous tree | Horizontal branch |
| Dark-eyed Junco (**Junco hyemalis**) | 15 | 0.2 | 0.0-2.7 | Ground, dead coniferous tree | Overhanging grass, log, litter, rock; rotted stub cavity |
| Chipping Sparrow (**Spizella passerina**) | 29 | 3.4 | 0.0-15.2 | Coniferous tree, deciduous shrub, evergreen shrub, ground | Horizontal branch, upright crotch |

[a]Specific identification of the **Empidonax** flycatchers could not be confirmed.

story layers (less than 6 m) of the Douglas-fir forest. There are interpretive limitations in this sort of listing because not all nests were found and some nests are more easily detected than others.

Nesting heights of some species showed wide vertical ranges. Nests of the Northern Flicker (*Colaptes auratus*), a primary hole-nesting species, ranged from less than 2 m to 40 m above the ground. Those of the Mountain Chickadee (*Parus gambeli*) (3-39 m) and Red-breasted Nuthatch (*Sitta canadensis*) (3-32 m), secondary hole-nesting species, also had wide ranges in nesting heights. In general, those species with high average nesting heights had wide vertical ranges in nesting heights. Those species with intermediate average nesting heights (Chipping Sparrow [*Spizella passerina*], Western Tanager [*Piranga ludoviciana*], Hairy Woodpecker [*Picoides villosus*], Ruby-crowned Kinglet [*Regulus calendula*], Solitary Vireo [*Vireo solitarius*]) also had intermediate vertical ranges in nesting heights. Ground and shrub layer nesters (Townsend's Solitaire [*Myadestes townsendi*], MacGillivray's Warbler [*Oporornis tolmiei*], Black-backed Woodpecker [*Picoides arcticus*], Dark-eyed Junco [*Junco hyemalis*]) had restricted ranges in nesting heights.

Although overlap existed, each of the three primary hole-nesters in the forest nested in different height categories: the Northern Flicker largely in the overstory layer, the Hairy Woodpecker in the midstory zone, and the Black-backed Woodpecker in the shrub layer. Conner *et al.* (1975) also found nesting height differentiation among four species of woodpeckers in Virginia.

Nest substrate and nest placement of the 25 species (Table 1) generally matched that described in the literature (e.g., Bent 1968, Harrison 1979). Among the species for which nest sample size was larger than one, none was plant specific in choice of nesting substrate, although one species (MacGillivray's Warbler) apparently preferred deciduous over evergreen shrubs. Sample sizes for most bird species were too small to detect preferences for specific plant species as nesting sites.

### Breeding Bird Densities

Breeding bird density ranged from 192 to 252 pairs per 40 ha on the study plots (Table 2); 18 to 19 species were territorial on the five southeast-facing plots and 21 species were territorial on the north-facing plot (Plot 2). Parts of the north-facing plot had a dense undergrowth of deciduous shrubs and saplings. The most numerous species, each making up more than 5 percent of the population, were the Swainsons's Thrush (*Catharus ustulatus*), Western Tanager, *Empidonax* flycatcher, Chipping Sparrow, Red-breasted Nuthatch, Dark-eyed Junco, Mountain Chickadee, MacGillivray's Warbler, and Yellow-rumped Warbler (*Dendroica coronata*). Those nine taxa accounted for 75 percent of the breeding bird population. Other common species, each comprising 2 to 5 percent of the population, were the Calliope Hummingbird (*Stellula calliope*), Solitary Vireo, Nashville Warbler (*Vermivora ruficapilla*), Brown Creeper (*Certhia americana*), Cassin's Finch (*Carpodacus cassinii*), and Townsend's Warbler (*Dendroica townsendi*). There were 960 to 1,261 individual breeding birds per $km^2$. Hole-nesting species (Northern Flicker, Hairy Woodpecker, Black-backed Woodpecker, Mountain Chickadee, White-breasted Nuthatch [*Sitta carolinensis*], Red-breasted Nuthatch, Brown Creeper, Winter Wren [*Troglodytes troglodytes*]) made up 21 percent of the breeding bird population.

When expressed as standing crop biomass, the Swainsons's Thrush was the pre-

TABLE 2. Population density and other attributes of the breeding birds on six study plots grouped by nesting height categories.

| Species and nesting height category | Weight[a] (g) | Foraging category[b] | Population density (pairs/40 ha) 1 | 2[c] | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|
| | | | OVERSTORY (>12 m) | | | | | |
| Northern Flicker | 145.0 | GGI | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Olive-sided Flycatcher | 31.5 | ASI | +[d] | + | —— | —— | + | + |
| Mountain Chickadee | 12.0 | TGI | 15.0 | 15.0 | 17.5 | 15.0 | 13.7 | 10.0 |
| Red-breasted Nuthatch | 10.1 | TGO | 18 7 | 17.5 | 17.5 | 15.0 | 18.7 | 22.5 |
| Western Tanager | 29.0 | FGI | 27.5 | 20.0 | 22.5 | 25.0 | 20.0 | 15.0 |
| Cassin's Finch | 27.6 | GGG | 6.2 | 5.0 | 5.0 | + | 5.0 | 6.2 |
| **Overstory Subtotals** | | | 69.9 | 60.0 | 65.0 | 57.5 | 59.9 | 56.2 |
| | | | MIDSTORY (6-12 m) | | | | | |
| Hairy Woodpecker | 69.8 | TDI | 7.5 | 5.0 | 2.5 | —— | 1.2 | 2.5 |
| Golden-crowned Kinglet (*Regulus satrapa*) | 5.1 | FGI | + | 3.7 | 3.7 | 3.7 | —— | + |
| Ruby-crowned Kinglet | 6.1 | FGI | + | 5.0 | + | —— | 5.0 | 3.7 |
| Yellow-rumped Warbler | 13.1 | FGI | 12.5 | 20.0 | 13.7 | 12.5 | 11.2 | 5.0 |
| **Midstory Subtotals** | | | 20.0 | 33.7 | 19.9 | 16.2 | 17.4 | 11.2 |
| | | | UNDERSTORY (3-6 m) | | | | | |
| Calliope Hummingbird | 2.5 | FNI | 6.2 | 6.2 | 7.5 | 5.0 | 11.2 | 7.5 |
| **Empidonax** spp. | 9.5 | ASI | 15.0 | 25.0 | 20.0 | 10.0 | 27.5 | 25.0 |
| White-breasted Nuthatch | 17.4 | TGO | —— | + | + | —— | —— | 2.5 |
| Brown Creeper | 8.0 | TGI | + | 6.2 | + | 10.0 | 6.2 | 7.5 |
| American Robin | 88.0 | GGI | 3.7 | 2.5 | 6.2 | 2.5 | 3.7 | 5.0 |
| Swainson's Thrush | 30.0 | FFO | 11.2 | 31.2 | 25.0 | 30.0 | 17.5 | 17.5 |
| Solitary Vireo | 15.3 | FGI | 7.5 | 7.5 | 1.2 | 11.2 | 5.0 | 6.2 |
| Townsend's Warbler | 8.5 | FGI | 2.5 | 8.7 | 10.0 | 6.2 | + | + |
| Chipping Sparrow | 12.2 | GGG | 22.5 | 20.0 | 22.5 | 15.0 | 18.7 | 22.5 |
| **Understory Subtotals** | | | 68.6 | 107.3 | 92.4 | 89.9 | 89.8 | 93.7 |
| | | | SHRUB (0.5-3 m) | | | | | |
| Black-backed Woodpecker | 73.0 | TDI | —— | + | —— | + | —— | + |
| Hermit Thrush | 25.6 | FFO | 10.0 | + | + | 1.2 | + | —— |
| Townsend's Solitaire | 31.7 | FFO | 3.7 | 3.7 | 1.2 | 2.5 | —— | —— |
| MacGillivray's Warbler | 11.4 | FGI | 6.2 | 17.5 | 12.5 | 13.7 | 16.2 | 16.2 |
| **Shrub Subtotals** | | | 19.9 | 21.2 | 13.7 | 17.4 | 16.2 | 16.2 |
| | | | GROUND (<0.5 m) | | | | | |
| Winter Wren | 8.9 | GGI | —— | + | —— | 2.5 | —— | + |
| Nashville Warbler | 8.3 | FGI | + | 12.5 | 3.7 | —— | 13.7 | 8.7 |
| Dark-eyed Junco | 17.7 | GGG | 13.7 | 17.5 | 17.5 | 16.2 | 16.2 | 18.7 |
| **Ground Subtotals** | | | 13.7 | 30.0 | 21.2 | 18.7 | 29.9 | 27.4 |
| **Total Species** | | | 18 | 21 | 19 | 19 | 18 | 19 |
| **Total Pairs per 40 ha** | | | 192 | 252 | 212 | 200 | 213 | 205 |
| **Total Individuals per km²** | | | 960 | 1261 | 1061 | 998 | 1066 | 1023 |
| **Species Diversity Index** | | | 2.69 | 2.81 | 2.67 | 2.68 | 2.69 | 2.71 |

[a]Species weights from Salt (1957), Kilgore (1971), and Linsdale (1936).

[b]FNI=foliage nectivore-insectivore, FGI=foliage gleaning insectivore, FFO= foliage feeding omnivore, ASI=aerial sally feeding insectivore, TGO=timber gleaning omnivore, TGI=timber gleaning insectivore, TDI=timber drilling insectivore, GGI=ground gleaning insectivore, GGG=ground gleaning granivore.

[c]A north-facing plot; all other plots were generally southeast-facing.

[d]+indicates that bird was observed on the plot but too infrequently to delineate a territory.

dominant species, followed by the Western Tanager, Northern Flicker, American Robin (*Turdus migratorius*), Dark-eyed Junco, Chipping Sparrow, and Hairy Woodpecker. Those seven species made up over 66 percent of the standing crop biomass of the breeding avifauna. Total standing crop biomass on the six study plots ranged from 189 to 237 g/ha (Table 3).

In addition to the 26 breeding bird species listed in Table 2, others commonly observed were the Northern Goshawk (*Accipiter gentilis*), Sharp-shinned Hawk (*Accipiter*

TABLE 3. Standing crop biomass of breeding birds on six study plots grouped by nesting height categories.

| Nesting height category | Standing crop biomass (g/ha) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | Mean |
| Overstory | 84 | 72 | 77 | 71 | 72 | 66 | 73.7 |
| Midstory | 34 | 33 | 19 | 9 | 13 | 13 | 20.2 |
| Understory | 62 | 95 | 94 | 86 | 75 | 85 | 82.8 |
| Shrub | 22 | 16 | 9 | 13 | 9 | 9 | 13.0 |
| Ground | 12 | 21 | 17 | 15 | 20 | 20 | 17.5 |
| Totals | 214 | 237 | 216 | 194 | 189 | 193 | 207.2 |

*striatus*), Red-tailed Hawk (*Buteo jamaicensis*), Spruce Grouse (*Dendragapus canadensis*), Ruffed Grouse (*Bonasa umbellus*), Gray Jay (*Perisoreus canadensis*), Common Raven (*Corvus corax*), Pine Siskin (*Carduelis pinus*) and Red Crossbill (*Loxia curvirostra*).

Other species less frequently observed included the Cooper's Hawk (*Accipiter cooperii*), Golden Eagle (*Aquila chrysaetos*), Great Horned Owl (*Bubo virginianus*), Northern Pygmy-Owl (*Glaucidium gnoma*), Pileated Woodpecker (*Dryocopus pileatus*), White-headed Woodpecker (*Picoides albolarvatus*), Steller's Jay (*Cyanocitta stelleri*), Clark's Nutcracker (*Nucifraga columbiana*), Varied Thrush (*Ixoreus naevius*), Black-headed Grosbeak (*Pheucticus melanocephalus*), and Evening Grosbeak (*Coccothraustes vespertinus*).

### Foraging Categories

Species may be categorized by foraging substrate (foliage, timber, ground, or air) and dietary habits (insectivore, granivore, or omnivore). Foraging categories listed for each species in Table 2 are based on those developed by Diem and Zeveloff (1980).

The 26 breeding bird species were in nine foraging categories. Foliage-feeders were numerically dominant among all species and made up the largest proportion of all foraging categories. Among the foliage-feeders, insectivorous species were predominant. Three species (Chipping Sparrow, Cassin's Finch, and Dark-eyed Junco) were granivorous. The aerial-sally category was represented by the Olive-sided Flycatcher (*Contopus borealis*) and the *Empidonax* group. Six species were classified as either timber-gleaning or timber-drilling foragers.

Wiens (1978) showed that foliage-feeding forms numerically dominate the avifauna in North American coniferous forests, with ground-feeding, timber-foraging, and aerial feeders less important in decreasing order. The avifauna of the Douglas-fir forest generally fits this pattern.

With few exceptions, foraging categories in Table 2 are different for each species listed in a given nesting height stratum. Each of the species in both the overstory and ground layer nesting height categories has different foraging strategies. In the understory zone, only the solitary Vireo and the Townsend's Warbler are in the same foraging category; in the shrub layer, only the Hermit Thrush (*Catharus guttatus*) and the Townsend's Solitaire are in the same foraging category. However, in the midstory nesting height layer three of the four species listed have the same feeding strategy.

### Nesting Height Categories

Tables 2 and 3 also show the numbers and standing crop biomass of birds nesting at

different heights in the Douglas-fir forest. The understory layer (3 to 6 m) contained 43 percent of the number and 40 percent of the biomass of the nesting avifauna. The overstory layer (above 12 m) had about 29 percent of the number and 36 percent of the nesting bird biomass. The ground (less than 0.5 m), shrub (0.5 to 3 m), and mid-story (6 to 12 m) layers, each had about a tenth or less of the nesting bird population. Numerically, almost two-thirds of the avifauna nested in the lowest three strata (less than 6 m) of the Douglas-fir forest. Kilgore (1971) reported similar stratal importance values for nesting height categories in a California sequoia forest.

### Bird Population Comparisons

Table 4 summarizes the relatively scarce quantitative information on breeding bird

TABLE 4. Features of breeding bird communities in North American interior Douglas-fir forests.[a]

| State | Tree dominants | Censuses | No. species | Density (indiv/km²) | Standing crop biomass (g/ha) | Reference |
|---|---|---|---|---|---|---|
| Colorado | Douglas-fir-ponderosa pine | 1 | 15 | 513 | 104 | Snyder, 1950 |
| Montana | Douglas-fir-lodgepole pine | 1 | 10 | 890 | 126 | Frissell, 1973 |
| Montana | Douglas-fir-ponderosa pine | 1 | 20 | 950 | 199 | Manuwal, 1968 |
| Arizona | Douglas-fir-ponderosa pine | 1 | 29 | 1582 | 458 | Franzreb and Ohmart, 1978 |
| Idaho | Douglas-fir-lodgepole pine | 1 | 23 | 2152 | 615 | Johnston, 1949 |
| Idaho | Douglas-fir-ponderosa pine | 6 | 18-21 | 960-1261 | 189-237 | This study |

[a]In part from Wiens (1975).

populations of interior Douglas-fir forests in North America. Most of these censuses were conducted using spot-mapping techniques (International Bird Census Committee 1970) or similar methods. Census plots were variable in size and ranged from 8 to 18 ha. The forest stands sampled had varying degrees of disturbance. All of the stands had Douglas-fir as the dominant tree in mixture with other tree species.

Including this study, species richness ranged from 10 to 29 and density varied from 513 to 2,132 with a mean of 1,132 per km². Standing crop biomass ranged from 104 to 615 g/ha with a mean of 250 g/ha. Although many geographical differences existed, the most typical species in the Douglas-fir forests sampled were the Ruby-crowned Kinglet, *Junco* spp., Yellow-rumped Warbler, Mountain Chickadee, Hermit Thrush, Red-breasted Nuthatch, American Robin, Western Tanager, Pine Siskin, and Hairy Woodpecker. These species, present in most of these censuses, may be regarded as the most representative species or genera in the Douglas-fir forests of North America.

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# Stratiform Sedimentary Lead Sulfide Ores of Bonanza, Mine, Stevens County, Washington

## Abstract

Previous views as to the probable origin (replacement vein) of the lead ores of the Bonanza mine of northeastern Washington are rejected. Recent review of old data and the gathering of new data, especially textural data obtained by the study of polished ore specimens using reflecting microscopy, establish the sedimentary-type stratiform massive sulfide nature of the original deposit and its subsequent metamorphism.

## Purpose

The purpose of this paper is to demonstrate that the Bonanza mine ores are not vein or replacement deposits as has been previously proposed, but are stratiform strata-bound sedimentary sulfide deposits which have had their sedimentary aspect considerably modified by later deformation and subsequent annealing. This revision in our understanding of the mode of formation of this deposit requires a corresponding modification of our approach to exploration for its extension, as well as to the search for similar deposits elsewhere in northeastern Washington.

## History

The Bonanza mine in the north half of sec 11, T37N, R37E, Stevens County, Washington, about 123 km NNW of Spokane, Washington (Figure 1), was discovered in 1885. Its production prior to 1907 was sporadic and presumably small. Production was continuous from 1907 through 1920, intermittent from 1920 to 1942, then continuous until 1952 when the mine closed. About 86 percent of the ore tonnage was mined during the 11 years preceding the closing. Total recorded production from 1907 to 1952 (Fulkerson and Kingston 1958) was 25 x $10^6$ lbs of lead, 22 x $10^3$ lbs of copper, and 239 x $10^3$ ounces of silver, from 102 x $10^3$ tons of ore. This corresponds to an overall grade of about 12.2 percent lead and 2.3 ounces of silver per ton. Ore was mined on six levels over a dip length of about 160 m and an elevation range of 107 m. Although the aggregate length of sulfide mineralization is not known, the mine level aggregate length, excluding the Gibbs crosscut, is 1.96 km. Since the mine closed in 1952, both shafts and the Gibbs access crosscut have collapsed so that all mine workings are inaccessible.

## General Geology

The deposit underlines a low, grassy hill on which outcrops are scarce, small, and inconspicuous, probably constituting less than 1 percent of the surface above the mine workings. This, together with the lack of mine access, means that our knowledge of the

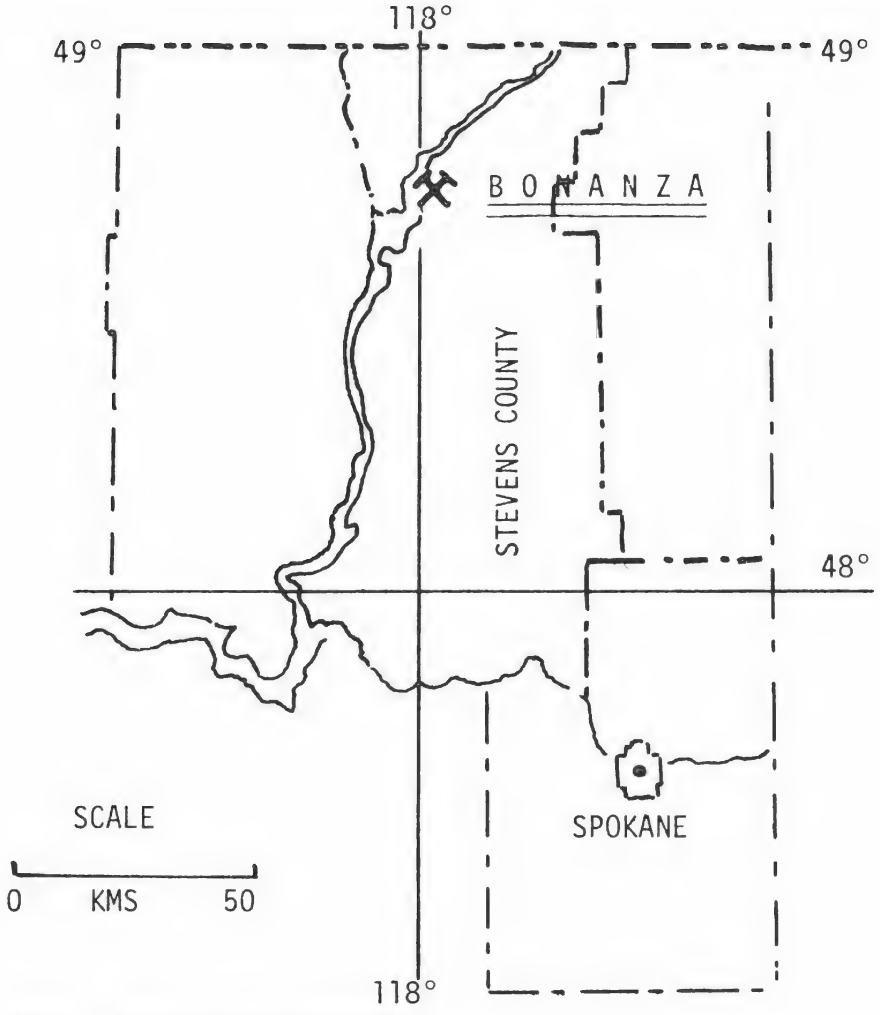


Figure 1. Location map of the Bonanza Mine.

geologic setting of the ore body is limited to brief descriptions provided by early authors (Bancroft 1914, Weaver 1920, Patty 1921, Hunting 1956), unpublished data of Washington State's Division of Geology and Earth Resources, and data gathered by the author from surface outcrops and mine dump specimens.

The geologic setting of the ore deposit is one of a gently north-plunging upright antiform, with associated minor folds, in argillite and phyllitic argillite. Ore sulfides are conformable with the bedding of the host rocks and both are folded. Furthermore, both are cut, drag folded, and displaced by major north-striking faults dipping moderately steeply to the west in the central part of the mine workings and to the east on the eastern mine workings. The age of the strata is probably Ordovician to Devonian (Las-

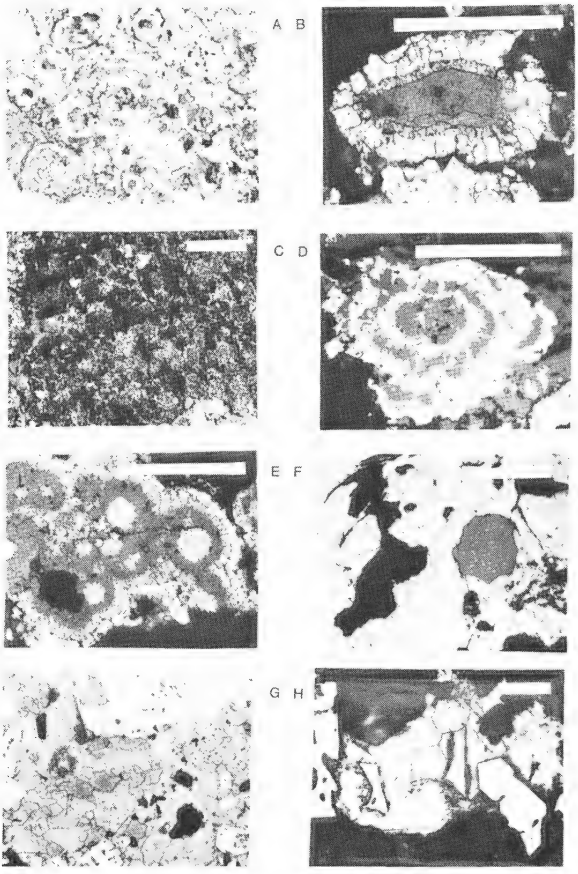


Figure 2. Length of white bar in each figure represents 0.10 mm. Dark gray to black areas are non-reflecting gangue (host rock silicates, quartz, siderite).
A through E: textures diagnostic of sedimentation.
F and G: textures diagnostic of metamorphism, including annealing.
A: Atoll texture in ultra-fine grained pyrite (light gray; etched*) and pyrrhotite (gray).
B: Atoll texture in pyrite (outer double layer; white and light gray; etched) and sphalerite (core; gray).
C: Composite mass of framboidal pyrite (etched).
D: Atoll texture in pyrite (white) and sphalerite (light gray).
E: Composite pyrite-sphalerite body with a 2-layer pyrite rind consisting of an outer fine grained layer and an inner ultra-fine grained layer, surrounding a core of sphalerite (gray) containing several spherical pyrite framboids (etched).
F: Sub-spherical sphalerite (dark gray) with speckles of exsolved(?) chalcopyrite, surrounded by galena (light gray) and gangue (black).
G: Porphyroblasts of pyrite (white) with inclusions of galena (light gray; etched**) surrounded by intergrown polygonal galena (light gray; etched) and pyrrhotite (gray).
H: Granoblastic polygonal galena (light gray; etched) and porphyroblastic pyrite (white) with inclusions of galena (dark gray; etched).

*Pyrite etchant: 98 parts concentrated nitric acid to 2 parts methanol. Apply at room temperature for 15 seconds to 4 minutes.

**Galena etchant: 1 part concentrated HCl to 3 parts thiourea solution (100 grams per liter). Etch time is 1 to 2 minutes at approximately 80°C.

kowski 1982). Folding and faulting are probably early Cretaceous and post-Cretaceous, respectively, in conformity with structural data applicable to similar strata in neighboring parts of northeastern Washington.

### Geology of Ore Horizon

Overall, the ore horizon strikes northeasterly and dips 30 to 55 degrees northwesterly in the western mine workings; about east-west with dips of 10 to 35 degrees northerly in the central part; and northwest with dips from 25 to 55 degrees easterly in the eastern mine workings. Wide divergences from these general attitudes occur wherever the strata and sulfides are involved in minor folds. Ore is localized along the contact of chlorite-sericite phyllite below (footwall) and black graphitic argillite above (hanging wall), conforming to beds and bedding. Sulfide horizon thickness ranges from a few cms to 6 m, most commonly in the range of 2 m to 2½ m. The greatest thicknesses are at fold hinges. It is reported (in the unpublished data files of Washington Division of Geology and Earth Resources) that in the eastern part of the mine the ore mineralization grades laterally into the host rock argillite and that the margins of the sulfide bodies contain a higher proportion of quartz and pyrite than do the central parts.

Mineralization is very fine-grained galena with about equal amounts of pyrite, several percent of pyrrhotite, and very little sphalerite. Gangue minerals include the rock-forming minerals of the argillite host together with siderite, quartz, barite, and a little calcite. Typical sulfide-rich hand specimens are strongly banded owing to the changing proportions of the various sulfides and gangue minerals.

### Ore Petrography

Textures observed in hand specimens and in polished sections using the reflecting microscope are of two distinctly different origins—sedimentary and metamorphic.

*Observed textures indicative of sedimentation* include:

(1) thin interbedding of sulfides and rock-forming silicates common in hand specimens and in polished section
(2) nodular, colloform, and framboidal textures (Figures 2A, 2C, 2E)
(3) atoll textures in pyrite, sphalerite and galena (Figures 2B, 2D)

*Observed textures indicative* of metamorphism and annealing* are:

(1) crumples in bedding of sulfides and silicates
(2) thickening of galena layers in fold hinges
(3) numerous pyrite porphyroblasts (Figures 2G, 2H)
(4) granoblastic polygonal galena (Figures 2G, 2H)
(5) annealing twins in sphalerite

### Conclusions

Most previous authors have concluded that the Bonanza ore body is a vein deposit formed by the replacement of host rocks within a shear zone. The present writer was the first to suggest that the deposit may be a massive sedimentary sulfide deposit (Mills 1977, p. 48). During the present review of old data and the gathering of new data,

*For the benefit of the reader who may not be familiar with the recognition and interpretation of metamorphic textures in lead-zinc ores, the following references will be helpful: McDonald 1970; Davis 1973; Mills 1976; Pederson 1980; Frizzo, Mills, and Visonà 1982.

little or nothing was found that is compatible with, or diagnostic of, a replacement origin. On the other hand, data both compatible with, or diagnostic of, a primary sedimentary forming of the ores and their subsequent metamorphism are abundant and compelling. The data discussed and detailed in this paper, such as the stratiform and stratabound nature of the ores, the folded character of both the ore horizon and the graphitic host rocks, the simple ore mineralogy, and especially the textures of the ores, are abundant evidence of their primary sedimentary origin modified by subsequent metamorphism.

Mineral deposits exploration plans and procedures are based on implicit or explicit understanding of how such deposits were formed. Clearly, the chances of success in the search for extensions of the Bonanza mine ores, or for finding similar deposits elsewhere in northern Washington, are much greater when it is appreciated that the Bonanza ore body is a marine sedimentary deposit, not a hydrothermal vein deposit.

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# Habitat Orientations of Forest Birds in Southeastern Alaska

## Abstract

Spring/summer bird surveys were conducted in coastal forest stands in southeast Alaska in 1978 and 1979. The 10 habitat categories surveyed included riparian and nonriparian situations and a successional sequence from new clearcuts to old growth. For 35 species recorded, over half of total observations were contributed by the Winter Wren (*Troglodytes troglodytes*), Dark-eyed Junco (*Junco hyemalis*), Golden-crowned Kinglet (*Regulus satrapa*), Chestnut-backed Chickadee (*Parus rufescens*), and Orange-crowned Warbler (*Vermivora celata*). Lowest species richness occurred in new clearcuts and in young second-growth sawtimber. Riparian situations supported greater avian abundance and species richness than did riparian stands of the same successional stage. Trends in avian occurrence are related to stand structural changes that occur through the successional sequence. Silvicultural practices such as thinning may have potential to enhance habitat structure and avian diversity in managed second-growth stands.

## Introduction

Southeast Alaska supports an important commercial forest of western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) that is managed for timber, wildlife, and other uses by the USDA Forest Service. Recent timber harvest activities are introducing change into the habitats occupied by resident wildlife. An interspersion of successional stages is being created as the predominantly old-growth forest is clearcut and managed on an approximately 100-year rotation.

Little information is available on the birds of the coastal western hemlock-Sitka spruce forest. Buckner *et al.* (1975) described the breeding bird communities of northern Vancouver Island. Webster (1941, 1950, 1978) has published notes on his observations of southeast Alaska birds. Recent surveys conducted in southeast Alaska, however, remain unpublished (Gibson and MacDonald 1975, Gibson 1976, Noble 1977).

The Forest Service has supported bird surveys on its southeast Alaska lands for use in management programs. In this paper we summarize those surveys, describe the habitat orientations of species observed, and relate our findings to existing forest management practices.

## Study Area and Methods

We conducted the surveys on Kosciusko and Prince of Wales Islands (55-56°N,

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133°W). The maritime climate has mean temperatures of 5-20° C in summer and -10-5° C in winter. Heavy rainfall, up to 400 cm annually, is normal. Vegetation of the area is interspersed old-growth forest, bog communities (muskegs), and cutover forest in early successional stages. Numerous lakes, streams, and saltwater inlets occur within the area.

The surveys were conducted from late May to mid-July in 1978 and 1979. We established 78 transects, 300 m in length, in a variety of forest stands. About half the transects occurred within generally homogeneous stands of successional and old-growth forest. The transects were placed at least 50 m within the stand to avoid edge effect. Remaining transects were placed within riparian zones. In all, 10 combinations of successional stage and riparian/nonriparian status (henceforth, referred to as habitat categories) were represented.

Nonriparian habitat categories were shrub/forb stage clearcuts (< five years old), sapling/shrub stage clearcuts (11-17 years), pole stage clearcuts (30 years), second-growth sawtimber (75 years), and old-growth commercial forest. The second-growth sawtimber appeared to have windthrow as its origin. All nonriparian stands were judged to be of the closed western hemlock-Sitka spruce forest type of Viereck and Dyrness (1980).

Riparian habitat categories were old-growth forest associated with streams, lakes, muskegs, and saltwater inlets; and sapling/shrub stage clearcuts associated with streams. Of these, the muskeg-bordered stands were of the open lodgepole pine (*Pinus contorta*)-western hemlock forest type; lakeside stands were of the western hemlock-western red cedar (*Thuja plicata*) type; and stands associated with streams and saltwater inlets were of closed western hemlock-Sitka spruce (Viereck and Dyrness 1980).

Each bird transect received four morning and four evening visitations distributed throughout the sampling period. We alternated direction of travel on each visit. Morning and evening counts began 0.5 hr after sunrise (about 04:00 on 15 June) and 2.5 hr before sunset (about 21:30 on 15 June), respectively, and were completed in 2-3 hr. All birds seen or heard within 40 m of the transects were recorded. We determined the mean number of birds of each species observed per transect over the eight visitations, and used these values to assign arbitrary abundance classes. These were rare (<0.50), uncommon (0.51-1.00), common (1.01-5.00), very common (5.01-10.00), abundant (10.1-15.00), and very abundant (>15.00). Bird observability in the dense coastal forest varies greatly among habitats and species. We therefore did not attempt to estimate bird densities nor test for statistical differences among the habitat categories.

We sampled vegetation associated with each bird transect by plots that varied in size for the understory, midstory, and overstory layers (0.001 ha, 0.02 ha, and 0.05 ha, respectively). Vegetation attributes sampled were species composition and cover of shrubs and herbaceous plants; species composition, height, and density of saplings; and species, diameter at breast height (DBH), and density of poles, trees, and snags.

Our sources for nomenclature of plants and birds were Hulten (1968) and the A.O.U. check-list and supplement (American Ornithologists' Union 1982).

#### Results and Discussion

A total of 3,780 bird observations included 35 species. The five most abundant species, the Winter Wren, Dark-eyed Junco, Golden-crowned Kinglet, Chestnut-backed Chicka-

TABLE 1. Species and abundance class[1] of birds observed in 10 habitat categories within coastal forest of southeast Alaska.

| Species | Successional Forest | | | | | Old-growth Forest | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Shrub/ Forb | Sapling/ Shrub | Sapling/ Shrub*[2] | Pole | Young sawtimber | Nonriparian | Stream* | Lake* | Saltwater* | Muskeg* |
| Common Merganser **Mergus merganser** | | | R | | | | R | | | |
| Sharp-shinned Hawk **Accipiter striatus** | | | | | | R | | | | |
| Red-tailed Hawk **Buteo jamaicensis** | | | R | | | | | | | |
| Bald Eagle **Haliaeetus leucocephalus** | | | X | | | | | | X | R |
| Greater Yellowlegs **Tringa melanoleuca** | | | | | | | | | | X |
| Spotted Sandpiper **Actitis macularia** | | | X | | | | | | | |
| Northern Hawk-Owl **Surnia ulula** | | | | | | | | | | R |
| Rufous Hummingbird **Selasphorus rufus** | | | XX | | | | R | R | XX | R |
| Belted Kingfisher **Ceryle alcyon** | | | X | | | | R | R | R | |
| Yellow-bellied Sapsucker **Sphyrapicus varius** | | | XX | | | R | X | XX | XX | X |
| Hairy Woodpecker **Picoides villosus** | R | | X | | | | | R | XX | R |
| Western Flycatcher **Empidonax difficilis** | | | X | XX | XX | XX | XXXX | XX | XXX | XX |
| Tree Swallow **Tachycineta bicolor** | XX | XX | XXXXX | | | | | | | X |
| Steller's Jay **Cyanocitta stelleri** | X | XX | X | XX | | | XX | X | X | XX |
| Common Raven **Corvus corax** | R | | | | | R | R | | | |
| Northwestern Crow **Corvus caurinus** | | | | | | | | | XX | |
| Chestnut-backed Chickadee **Parus rufescens** | | XX | XX | XXX | XXX | XXX | XX | XX | XXX | XXX |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Brown Creeper<br>**Certhia americana** | | | | | | | | | X | |
| American Dipper<br>**Cinclus mexicanus** | | | X | | | | | | | |
| Winter Wren<br>**Troglodytes troglodytes** | XXXXX | XXX | XXXX | XXX | XXX | XXX | XXX | X | XX | XX |
| American Robin<br>**Turdus migratorius** | R | | X | XX | | | | R | | XX |
| Varied Thrush<br>**Ixoreus naevius** | | X | R | XX | X | XX | XX | XX | XX | X |
| Hermit Thrush<br>**Catharus guttatus** | X | XX | X | XX | XX | XX | XX | X | XX | XX |
| Swainson's Thrush<br>**Catharus ustulatus** | | R | XX | XX | | | XX | | XX | X |
| Golden-crowned Kinglet<br>**Regulus satrapa** | | R | | XX | XXXX | XXX | XXX | XXX | XXX | X |
| Ruby-crowned Kinglet<br>**Regulus calendula** | | | R | XX | | | | | | R |
| Orange-crowned Warbler<br>**Vermivora celata** | R | XX | XXXX | X | | XX | X | XX | XX | XX |
| Yellow Warbler<br>**Dendroica petechia** | | | R | | | | | | | |
| Townsend's Warbler<br>**Dendroica townsendi** | | | R | X | XX | XXX | XX | XX | XX | X |
| Wilson's Warbler<br>**Wilsonia pusilla** | | | R | | | R | R | R | | |
| Pine Siskin<br>**Carduelis pinus** | | | X | | | | XXX | XX | XX | XX |
| Dark-eyed Junco<br>**Junco hyemalis** | XXX | XXX | XXXXX | X | | XX | XX | XXX | X | XXXX |
| Fox Sparrow<br>**Passerella iliaca** | R | XXX | | XXX | | | | | | |
| Lincoln's Sparrow<br>**Melospiza lincolnii** | | | XX | | | | | XX | XX | XX |
| Song Sparrow<br>**Melospiza melodia** | | X | XX | | | | | | R | |
| Species Richness | 10 | 12 | 27 | 14 | 7 | 13 | 18 | 18 | 21 | 22 |

[1]Abundance classes are rare (R), uncommon (X), common (XX), very common (XXX), abundant (XXXX), and very abundant (XXXXX).

[2]Asterisk indicates habitat within riparian zones.

dee, and Orange-crowned Warbler contributed 57 percent of total observations. Species richness (number of species observed) within the habitat categories ranged from 7 to 27.

The Winter Wren was the only ubiquitous species; it occurred in all habitat categories. Species composition and richness were generally variable among habitat categories (Table 1), as was the structure of the habitat present.

#### Successional Forest

The early successional stages (shrub/forb and sapling/shrub) contained a well-developed shrub layer dominated by *Vaccinium* species (*V. alaskaense, V. ovalifolium,* and *V. parvifolium*) and *Rubus spectabilis.* The most common herbaceous plants were *Cornus canadensis, Rubus pedatus,* and several species of ferns. All clearcut stands were devoid of mature trees, and contained heavy accumulations of undecomposed slash on the ground. Nearly all snags had been felled in new (shrub/forb) clearcuts. Sapling/shrub and pole clearcuts had some snags remaining. Dense spruce and hemlock regeneration occurred as seedlings in shrub/forb stands and as saplings (<13 cm DBH) in sapling/shrub stands.

Plant growth beneath the second-growth sawtimber was sparse due to low levels of light. Ferns and scattered small *Vaccinium* plants occurred, although typically a vascular plant understory was lacking. The overstory consisted of dense spruce and hemlock trees mostly under 54 cm DBH.

Only three bird species were commonly observed in shrub/forb clearcuts (Table 1). The Winter Wren and Dark-eyed Junco nested within these stands, whereas Tree Swallow (*Iridoprocne bicolor*) use was limited to aerial foraging above. These species remained abundant in sapling/shrub clearcuts. Greater species richness characterized sapling/shrub stands. Of 12 species observed, eight were common to abundant in the nonriparian stands.

We noted several differences between the riparian and nonriparian situations for sapling/shrub clearcuts. We observed over twice as many species in the riparian clearcuts as in nonriparian stands of the same age. Species generally occurred at higher abundance levels in the riparian clearcuts. Fox Sparrows (*Passerella iliaca*), very common in the nonriparian stands, were apparently replaced by Lincoln's and Song sparrows (*Melospiza lincolni* and *M. melodia*) in riparian situations. Nests of Tree Swallows, Hairy Woodpeckers (*Picoides villosus*) and Yellow-bellied Sapsuckers (*Sphyrapicus varius*) were commonly observed in snags within the riparian clearcuts. Riparian zones in the moist coastal forest do not provide as much contrast with surrounding habitat as is the case in drier forest types. Some differences are apparent, however. Habitat features which we observed in riparian zones that likely affected avian occurrence were greater snag abundance, presence of deciduous red alder (*Alnus rubra*) trees, and lush growth of shrubs and herbaceous plants.

The single pole stand available for study contained clumps of dense shrubs, although the herbaceous understory was reduced relative to earlier successional stages due to partial closure of the coniferous canopy. The pole stand contained the same bird species as the nonriparian sapling/shrub stands except for the additional presence of the Western Flycatcher (*Empidonax difficilis*) and American Robin (*Turdus migratorius*) and absence of the Tree Swallow. Subsequent fieldwork in pole-age stands suggests to

us that the situation reported herein is not typical. Canopy closure in regenerating stands usually occurs between stand age 25 and 35, and results in a rapid decline of the understory vegetation (Alaback 1982). Our pole stand, however, retained a partially open canopy and well-developed understory. This probably accounted for the similarity in bird species occurrence to that of the sapling/shrub stage. We would expect a closed pole stand, with understory eliminated, to support fewer species. This prediction has been supported during our more recent activities within pole-age stands having varying degrees of canopy closure.

The simple habitat structure within second-growth sawtimber was paralleled by the low number, seven, of bird species present. Species abundant in earlier successional stages (e.g., the Orange-crowned Warbler and Dark-eyed Junco) were absent. Two additional species, the Townsend's Warbler and Golden-crowned Kinglet, contributed about half of total observations. Chestnut-backed Chickadees and Winter Wrens contributed another 40 percent of total observations. The Winter Wren was the only well-represented species associated with the forest floor; it used rootwads of windthrown trees as nest sites. In general, the lack of an understory beneath second-growth sawtimber restricted avian use to the canopy of the stand.

#### Old-Growth Forest

Habitat structure of old growth differed from second-growth sawtimber in several respects. All old-growth stands contained a patchy but well-developed understory of shrubs and herbaceous plants of the same species that dominated young clearcuts. Old-growth stands were uneven aged, and contained a diversity of tree sizes from saplings and poles to large ($>$165 cm DBH) trees. Snags of all sizes were present. Tree species composition of old growth varied among habitat categories. Nonriparian old growth consisted almost exclusively of western hemlock and Sitka spruce, as did the riparian old growth that occurred along streams and saltwater inlets. Old growth associated with lakes additionally contained about 20 percent western red cedar and Alaska cypress (*Chamaecyparis nootkatensis*), collectively. Old growth associated with muskegs averaged 45 percent of the red cedar and cypress, collectively, and 13 percent lodgepole pine in addition to hemlock and spruce.

Bird species associated with old growth that were absent or scarce in young stands were the Townsend's Warbler, Golden-crowned Kinglet, Western Flycatcher, Swainson's Thrush (*Catharus ustulatus*), and Pine Siskin (*Carduelis pinus*). The Fox Sparrow was the only common species in young clearcuts that was absent in old growth. Other species associated with early successional stands (e.g., the Orange-crowned Warbler, Dark-eyed Junco, and Steller's Jay (*Cyanocitta stelleri*) had been eliminated from second-growth sawtimber but were present once again in old growth. This pattern appears to be related to the shrub, sapling, and pole components that young stands and old growth contain in common, but that are lacking in second-growth sawtimber.

Common bird species of old growth that showed an orientation to riparian situations were the Western Flycatcher, Pine Siskin, and Lincoln's Sparrow. The Northwestern Crow (*Corvus caurinus*) was observed only in association with saltwater inlets, where it was common. We observed fewer species within nonriparian old growth than in any of the riparian old-growth habitat categories.

We observed other bird species within the study area that were not included in our

sample. Sightings of Goshawks (*Accipiter gentilis*), Great Horned Owl (*Bubo virginianus*), saw-whet owls (*Aegolius acadicus*), Pygmy Owls (*Glaucidium gnoma*), and the Red-breasted Nuthatch (*Sitta canadensis*) usually occurred in old-growth stands, and we suggest an association of these species with mature forest. We observed the Spruce Grouse (*Dendragapus canadensis*) in pole stage clearcuts and young sawtimber. Red-tailed Hawks (*Buteo jamaicensis*) were highly visible as they foraged over young clearcuts and open muskegs.

#### Relationships to Forest Management

The generalized pattern of avian succession in cutover stands in southeast Alaska may be summarized as follows. Old-growth forest supports a variety of bird species that are oriented to the understory, midstory, and canopy layers of the stand. Clearcutting initially reduces species richness of nesting birds to a very low level, but additional species are supported as the sapling and shrub layers develop. Species richness declines during the pole stage, following canopy closure and loss of the understory. It remains low as the stand develops into commercial-size sawtimber.

These relationships have important management implications. Studies of second-growth forest stands in southeast Alaska have determined that canopy closure begins about 15 years after clearcutting, and generally results in elimination of the vascular plant understory by stand age 25 to 35. This condition is projected to last until stand age 140 to 160 (Alaback 1982). An unmanaged stand would therefore be expected to support few bird species during most of its 100-year rotation.

Forest management practices have potential to promote greater structural diversity and bird species richness in second-growth stands. Silvicultural thinning during the sapling or early pole stage is routinely conducted in southeast Alaska to reduce competition and promote timber growth. This practice is expected to prolong existence of the understory. Subsequent thinning at later stages, when the timber has reached commercial size, would then be needed to carry the understory through the rotation. A second-growth management program is being developed by the Forest Service Alaska Region to examine these management approaches and their potential value in wildlife habitat management.

Our sampling procedures were not appropriate for detecting species that have large home ranges. Our casual observations of certain hawk and owl species suggest an association with old growth. The extent to which these or other species prefer or require old growth in southeast Alaska is unknown. The relationship is a significant one for forest management, however. Maintenance of stands in productive second growth may reduce optimal habitat for bird species that require old-growth forest.

The greater abundance and species richness of birds that we observed within riparian zones was evidence of the special value of these habitats. We observed that hole-nesting species made especially heavy use of available snags along riparian corridors. Snag management should therefore be a featured aspect of riparian habitat management within the southeast Alaska coastal forest.

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# Experimental Cattle Grazing in a Relatively Undisturbed Shrubsteppe Community

## Abstract

Yearling hereford steers were grazed for six to eight weeks in the spring months of April and May for three consecutive years on nine hectare pastures in a shrubsteppe community representative of the *Artemisia tridentata-Agropyron spictatum* association in undisturbed condition. Steers showed grazing preference for Cusick bluegrass (*Poa cusickii*) and hawk's beard (*Crepis atrabarba*). Three consecutive years of grazing diminished the amount of standing dead grass in the pastures by 50 percent but grazing did not significantly affect the ability of the plant community to sustain herbaceous shoot production in the fourth year when grazing was discontinued. Weight gains of steers averaged 24 kg per hectare during the grazing season with an average weight gain of 0.63 kg per day per animal. Trampling was the most obvious and persistent damage to the plant community. Trampling killed plants growing in fence corners at gates and near the water trough locations where steers tended to congregate. Trampled ground was promptly colonized by alien, annual plants especially cheatgrass (*Bromus tectorum*) and tumble mustard (*Sisymbrium altissimum*), but these plants did not invade other portions of the grazed pastures.

## Introduction

Cattle grazing has been practiced in the semi-arid shrubsteppe region of eastern Washington since the middle 1800s (Galbraith and Anderson 1971). Years of over-grazing has resulted in the demise of native perennial grasses and encouraged a massive invasion by Eurasian annuals, especially cheatgrass brome (*Bromus tectorum*) (Daubenmire 1970). Shrubsteppe plant communities without substantial invasions of cheatgrass and other alien annuals are scarce. One of the few places with shrubsteppe plant communities in relatively undisturbed condition, as judged by the scarcity of cheatgrass and the dominance of native perennial grasses and forbs, is the United States Department of Energy's Hanford Site located in Benton County, Washington (Rickard *et al.* 1976). This article describes the effects of three consecutive years of experimentally controlled cattle grazing in a shrubsteppe community in relatively undisturbed condition by comparing treatment (grazed) and control (ungrazed) pastures using measurements of plant biomass.

## Study Area

The vegetation of the study area is representative of the *Artemisia tridentata-Agropyron spicatum* association in relatively undisturbed condition as described by Daubenmire (1970). The study area is located at an elevation of 360 m on a gentle northeast facing slope of the Rattlesnake Hills on the U.S. Department of Energy's Hanford Site, Benton Co., Washington. A silt-loam soil at least one m deep overlying basalt rock provides the rooting substrate. The annual rainfall averages 25 cm. The plant community had not been grazed by livestock since 1943 when the land was incorporated into the Hanford Site.

The plant community supports populations of small mammals especially Townsend ground squirrels (*Spermophilus townsendi*) and Great Basin pocket mice (*Perognathus parvus*) (Hedlund and Rickard 1980). Jackrabbits (*Lepus californicus*) were never seen on the study area and the site was not visited by mule deer (*Odocoileus hemionus*). A portion of the plant community was burned by a wildfire in August of 1973. This called for the use of an adjacent control pasture that did not burn. In 1974 this unburned pasture served as a substitute for the original control pasture.

### Methods

Steer grazing was conducted using two small pastures, each 300 x 300 m (9 hectares), established in a large homogeneous community representative of the *Artemisia tridentata-Agropyron spicatum* association in relatively undisturbed condition. The grazed pastures were fenced, gated, and provided with a shared 500 gallon water trough and a block of salt. Adjacent pastures of the same size served as ungrazed controls. Fifteen head of 400-500 lb yearling hereford steers were rotated at weekly intervals between two "grazed" pastures in 1971 and also in 1972. In 1973, only one of the pastures was grazed using seven steers. This yielded three consecutive years of grazing on one 9 ha pasture. In 1974, the other previously grazed pasture was grazed by five steers. Steers were weighed as a group on the day they entered the pastures. The steers were removed from the pastures held in a pen without food or water for one day and then weighed.

Within the boundaries of each 9 ha pasture six 450 $m^2$, 15x30 m, areas called blocks were randomly located. These were not located in fence corners or adjacent to the fence lines where cattle paths tended to form. At each sampling period, two 0.5 $m^2$ circular frames were randomly located in each block and these were hand clipped of all above-ground plant parts for biomass determinations.

Living shoots were segregated from the dead shoots by hand sorting. Live shoot biomass was further segregated into five generalized botanical categories; perennial grasses, perennial forbs, half-shrubs, annual grasses, and annual forbs (Table 1). Shoots were oven-dried at 50°C for 72 hours and weighed. Grass crowns were cut off at ground

TABLE 1. Mean dry weight g per $m^2$ of live shoot biomass ± standard error at peak yields grouped by botanical categories in control and grazed pastures in 1974 (n = 16).

| Botanical Categories | Control pasture | % of total | Pasture with 3[1] years of grazing | % of total |
|---|---|---|---|---|
| Perennial grasses | 54 ± 7.7 | 78 | 46 ± 5.3 | 72 |
| Perennial forbs | 4.5 ± 3.6 | 7 | 4.3 ± 1.2 | 7 |
| Half-shrubs | 4.2 ± 2.0 | 6 | 4.7 ± 1.4 | 7 |
| Annual grasses[2] | 4.8 ± .70 | 7 | 5.7 ± 1.2 | 9 |
| Annual forbs | 1.4 ± .49 | 2 | 3.0 ± .73 | 5 |
| Total shoot phytomass | 69 | | 64 | |

Perennial grasses: **Agropyron spicatum, Poa sandbergii, Poa cusickii, Stipa thurberiana.**
Perennial forbs: **Crepis atrabarba, Astragalus purshii, Lupinus laxiflorus, Brodiaea douglasii, Calochortus macrocarpus, Lomatium macrocarpum** and others.
Annual grasses: **Bromus tectorum, Festuca octoflora.**
Annual forbs: **Draba verna, Microsteris gracilis, Descurainea pinnata, Plantago purshii.**
Annual forbs: **Draba verna, Microsteris gracilis, Descurainea pinnata, Plantago purshii.**
Half-shrubs: **Phlox longifolia, Erigeron filifolius, Antennaria dimorpha.**

[1]pasture not grazed in 1974.

[2]mostly **Festuca octoflora.**

level using a hacksaw blade. Crowns were not separated into live and dead parts. Litter was collected from the ground by using a gasoline powered suction device. Aliquots of grass crown and litter material were burned in a muffle furnace to obtain a measure of their ash content. Results are expressed as grams of crown or litter per $m^2$ with the ash subtracted from the total weights. Harvesting was done five times between March and June each year. In the years 1971 and 1972, six blocks were sampled in two pastures of both grazed and control treatments ($n = 24$). In 1973 and 1974 the number of blocks in each pasture was increased to eight, providing 16 harvested frames at each sampling date.

#### Results and Discussion

When the steers were introduced to the pastures in April of each year they selectively grazed cusick bluegrass, *Poa cusickii.* In the first week, virtually every bunch was grazed, some bunches were grazed down to crown level while others were only partially eaten. Bunches growing beneath the canopy spread of sagebrush, *Artemisia tridentata,* shrubs were protected by the shrubs' stiff branches and these clumps generally escaped being eaten. The palatability of cusick bluegrass to cattle has been previously noted by Rickard *et al.* (1975) and Uresk and Rickard (1976). In contrast, Sandberg bluegrass, *Poa sandbergii*, was seldom grazed. The most palatable forb was hawk's beard, *Crepis atrabarba.* At flowering time, its yellow blossoms were conspicuous throughout the ungrazed pastures but flowers were absent in the grazed pastures because shoots had all been removed by cattle grazing. Bluebunch wheatgrass, *Agropyron spicatum*, was selected after cusick bluegrass shoots became depleted as a forage source and it provided the bulk of cattle forage in the remainder of the grazing season. Sagebrush and half-shrubs, longleaf phlox, *Phlox longifolia,* and fleabane, *Erigeron filifolius*, were not grazed by cattle.

The shoot biomass on the "grazed" pasture in 1974, after being grazed for 3 consecutive years in 1971, 1972, and 1973 but rested in 1974, was compared with the shoot biomass from an adjacent ungrazed "control" pasture (Table 1). Total herbaceous shoot production at peak harvest in 1974 averaged 69 g per $m^2$ in the control pasture and 64 g per $m^2$ in the grazed pasture (Fig. 1). These means were not statistically different. Perennial grasses provided 78 percent of the total live shoot biomass on the control pasture and 72 percent on the grazed pasture (Table 1). Annual forbs were sparsely represented on both pastures and the most abundant annual grass was six week's fescue, *Festuca octoflora.* Controlled spring grazing did not have a measurble

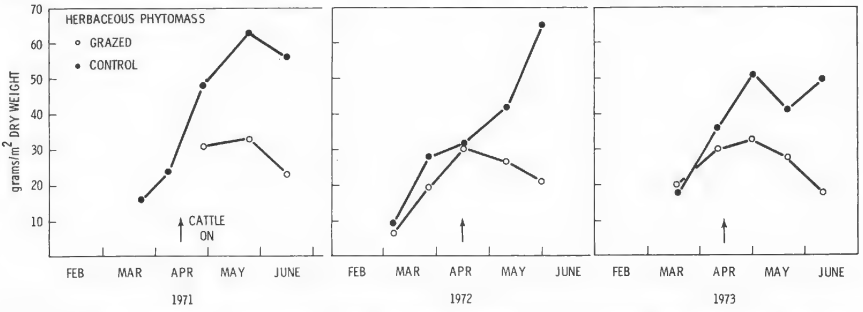


Figure 1. Comparison of herbaceous shoot biomass in grazed and ungrazed pastures from beginning to end of the growing season in 1974.

impact on shoot production after grazing was terminated. Nevertheless, spring grazing by steers did deleteriously affect the perennial grasses in other ways especially in their capacity to produce flowering culms (Rickard *et al.* 1975).

Grazing removed one-half to two-thirds of the new shoot growth in the years 1971, 1972, and 1973 (Fig. 2) and the amount of standing dead grass declined under grazing (Fig. 3). Crown weights averaged less on the grazed, than on the control, pasture but the total amount of litter showed no apparent changes under grazing (Fig. 3). Most of the plant material ingested by the steers remained on the pasture in the form of manure. Manure pats were especially concentrated near the water trough and in fence corners. In this way the presence of grazing cattle created a different distribution and form of dead plant matter on the grazed pastures as compared to the ungrazed pastures.

At places where steers tended to congregate (e.g., gate entries, water trough locations, and fence corners) cattle damaged the plants. Excessive trampling destroyed and/or

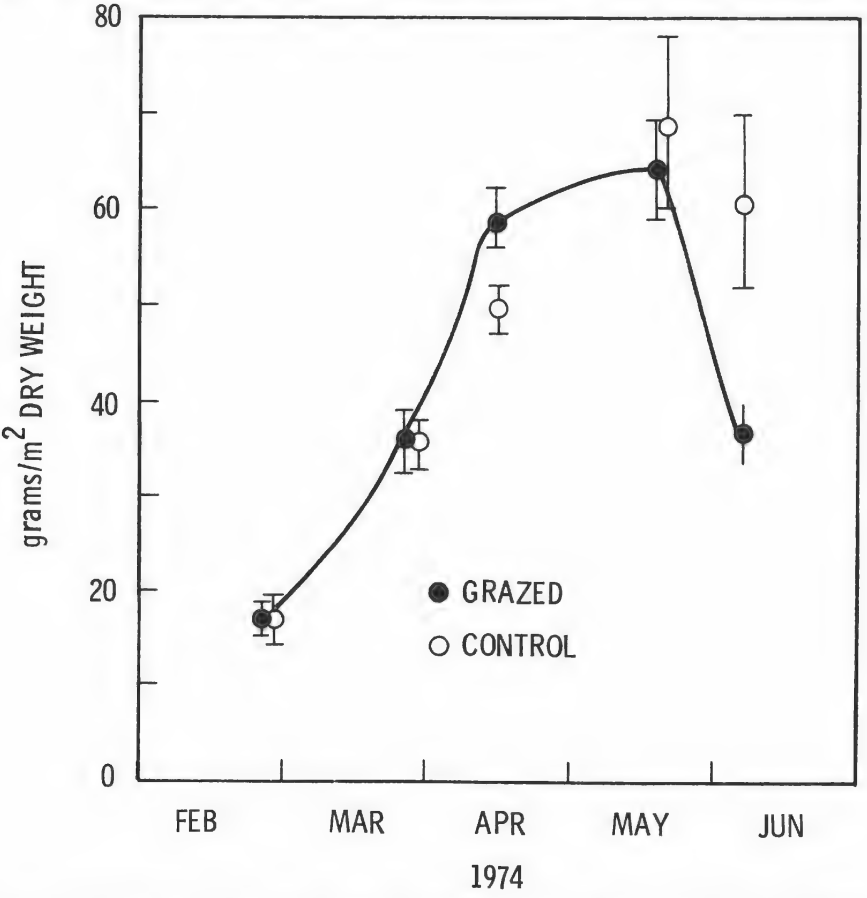


Figure 2. Comparison of live shoot biomass in grazed and ungrazed pastures in 1971, 1972, and 1973. The arrow indicates the date steers were introduced to the pastures.

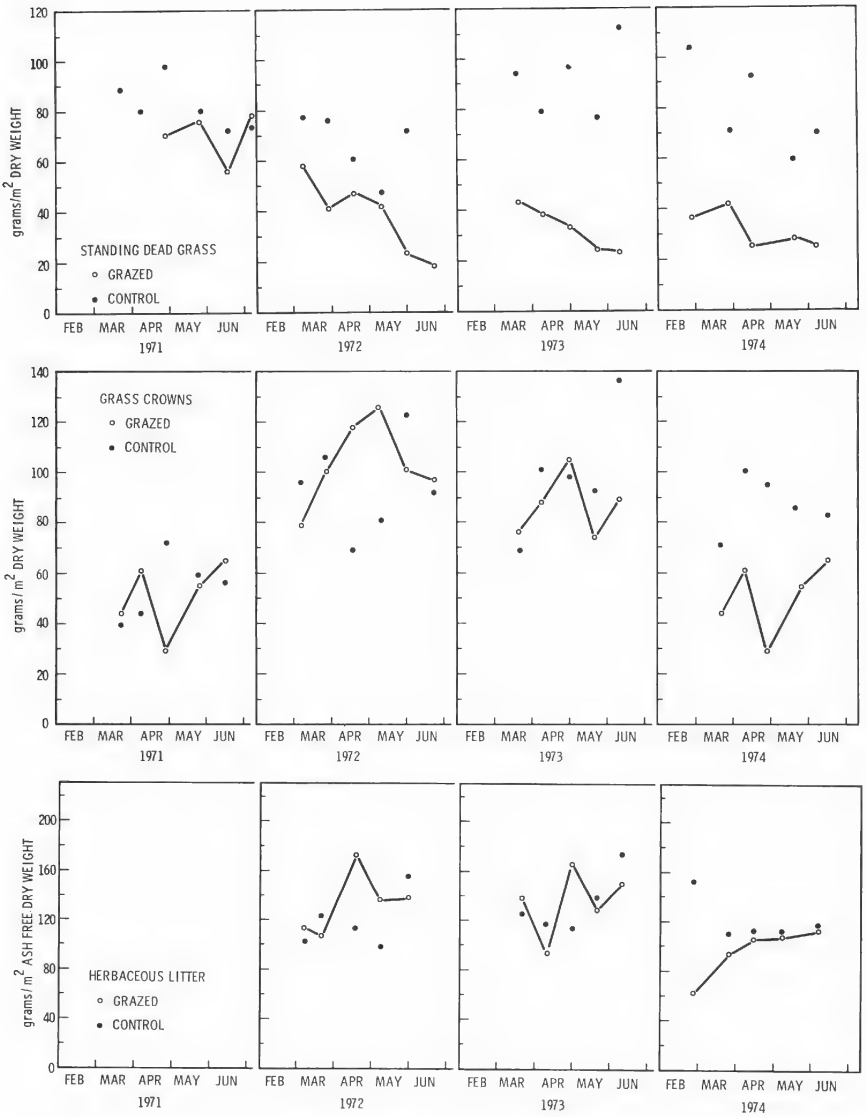


Figure 3. Comparisons of biomass of standing dead grass, grass crowns, and herbaceous litter in grazed and ungrazed pastures in 1971, 1972, and 1973.

damaged perennial grasses, forbs, and shrubs, and bared the soil. These bared places were invaded by cheatgrass and tumble mustard (*Sisymbrium altissimum*).

The average live weight gain of steers was 213 kg per 9 ha pasture per year (Table 2). This amounted to 24 kg per hectare. The average rate of live weight increase per steer was 0.63 kg per day of grazing use. This information provides some basis for judging the economic value of native shrubsteppe communities as a cattle grazing

TABLE 2. Weight gains of yearling steers during spring grazing in a 9 ha shrubsteppe pasture in the years 1971-1974.

| Year | Days of grazing | Animal days per pasture | Total wt. gain (kg) | Wt. gain per animal per day (kg) |
|---|---|---|---|---|
| 1971 | 58 | 435 | 308 | .78 |
| 1972 | 41 | 307 | 193 | .63 |
| 1973 | 49 | 343 | 156 | .45 |
| 1974 | 57 | 285 | 194 | .68 |
| Average | 51 | 342 | 213 | .63 |

resource and also a way to compare weight gains by cattle grazing in plant communities that have been strongly modified by years of grazing use or those revegetated with alien perennial bunchgrasses. For example, a recent grazing study using steers in crested wheatgrass pastures showed weight gains of 0.85-1.20 kg per day of grazing use (Hart *et al.* 1983).

Historically the shrubsteppe region of Washington has not been subjected to centuries of intensive ungulate herbivory. Bison became extinct about 2000 years ago and antelope were scarce (Osborne 1953). The virtual absence of large grazing ungulates in Washington suggests that shrubsteppe communities are especially vulnerable to grazing damage as compared to other kinds of perennial grass dominated communities (e.g., shortgrass prairies) developed over long periods of time under grazing stresses imposed by large mobile herds of bison and antelope.

Livestock grazing is one of man's most important biological uses of semi-arid shrubsteppe lands, especially lands that are not suitable for dryland wheat farming or for irrigated agriculture. Nevertheless, grazing research on shrubsteppe ranges has been minimal. The virtual absence of experimentally derived information concerning cattle grazing has encouraged the use of casual observations and untested theories in range management practice (Valentine 1979).

The invasion of shrubsteppe communities by cheatgrass, and ways to economically eradicate cheatgrass and replace it with more productive forage grasses, are regarded as important contemporary rangeland research topics (Young *et al.* 1979). The role of shrubsteppe communities as habitat for wildlife, especially on federally owned lands, is also beginning to attract an increasing amount of attention (McAdoo and Klebenow 1979). In the future, large land areas, such as the Hanford Site that have been protected from livestock grazing for 40 years, will become especially meaningful as baseline cases for making comparisons with continuously grazed plant communities in Washington and elsewhere in the strubsteppe region which extends from eastern Washington and Oregon to western Wyoming.

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# The Propagation of Sound from the Eruption of Mt. St. Helens on 18 May 1980

**Abstract**

The distribution of the sound produced by the major eruption of Mt. St. Helens on 18 May 1980 has been determined from the reports of over 4000 observers. A zone of silence extended in all directions to a distance of 100 km from the mountain, beyond which the sound was heard to a distance of 930 km, with the greatest intensity between 250 and 300 km. The observed atmospheric temperature and wind velocity gradients indicate that total refraction of the sound occurred at an altitude of 50 km. This has been confirmed by calculations based on the times of arrival of the sound recorded by barographs. The original pressure pulse from the eruption appears to have been slow rising, but steepened to the form of a shock wave during transmission through the atmosphere. Most observers reported the arrival of several sound pulses but it is not known if these originated at the eruption, or were produced by stratifications in the atmosphere.

## Introduction

During March 1980, seismologists were alerted by a sudden increase in the number of seismic disturbances under Mt. St. Helens, reaching a peak of over 100 earthquakes a day by the end of the month. It was clear that some form of eruption was likely to occur, and the residents of the forested area around the mountain were evacuated. In the following weeks there were a number of minor eruptions, and during the first two weeks of May a large bulge developed just below the summit on the northwest side of the mountain. This bulge grew at the rate of almost two meters a day. Eventually the bulge became so steep that it was no longer stable and at 0732 P.S.T. on 18 May 1980 a large part of the northwest face of the mountain slumped down into the valley and released a fountain of hot ash which continued to flow for many hours. Excellent descriptions of the eruption and its aftereffects were published in *National Geographic Magazine* in January and December 1981. A collection of 63 technical papers on the eruption has been published as Geological Survey Professional Paper 1250 (Lipman and Mullineaux 1981).

The closest observer who lived to tell his story was about nine miles from the mountain at the time of the eruption. This observer reported an absence of sound from the eruption itself, but about 20 minutes later people in the large metropolitan areas of Seattle, Vancouver, and Victoria were startled by a series of very loud bangs which they likened to the sound of guns fired a short distance away. These metropolitan centers were 160 to 300 km away from Mt. St. Helens and people expressed surprise that the intensity of the sound had not produced major damage in the region closer to the mountain. It seemed clear that this could be explained by the phenomenon known as upper-atmospheric transmission of sound.

## Sound Transmission in the Atmosphere

The reception of sound at large distances from the source has been reported frequently.

During the first world war, there were many reports of the gunfire from the western front being heard as far away as London, under some meteorological conditions. In 1917 there was a large explosion at a munitions factory at Silvertown in London and similar explosions at Oldebroek, Holland in 1923 and at Lacourtine, France in 1924 (Richardson 1942). In each of these cases there appeared to be a zone of silence extending from close to the source to a distance of about 100 km, with an increase of sound intensity beyond that radius. These observations were explained by a consideration of the temperature gradients in the atmosphere and lead to the hypothesis that at altitudes greater than about 15 km the atmospheric temperature increases with height and eventually reaches a value equal to and greater than that on the surface. In later years this hypothesis was confirmed when thermometers could be carried to high altitudes with balloons, aircraft and rockets. The phenomenon is now sufficiently well understood that it is possible to predict the intensity of the sound transmitted through the upper atmosphere if the size and location of the source are known and the temperature gradient in the atmosphere can be measured by balloon ascents. Such a precaution is always taken when large controlled explosions are detonated, because the return of sound from the lower regions of the atmosphere can be sufficiently intense to cause damage such as window breakage and plaster cracking.

The transmission, refraction, and focussing of sound in the atmosphere has been well discussed by several authors (Cox 1958; Cox *et al.* 1954; Pack 1958; Gilbert 1962; Thompson 1971; Reed 1972 a and b, 1983), and a brief qualitative discussion only, is presented here. The speed of sound in a gas is directly proportional to the square root of the absolute temperature. The pressure has no effect on the sound speed because the inverse ratio of pressure and density exactly cancels the influence of these two parameters. The relative humidity has a small influence on the sound speed but this is negligible compared with the effect of temperature. The temperature of the atmosphere close to the surface of the earth normally decreases linearly with altitude. This is particularly true early in the day before the radiant heat from the sun warms the earth, which in turn heats the air causing it to rise and produce turbulent mixing.

If sound moves through a gas in which there is a temperature gradient, the path of the sound will be refracted towards the cooler gas. In the early part of the day the temperature of the atmosphere decreases with altitude and as a result sound from a source on the surface of the earth is refracted upwards and even intense sounds may not be heard by a listener at ground level close to the source. The reverse effect may be observed at the end of a warm day over a cold surface such as a lake or the sea. In this situation the temperature of the air above the water increases with altitude and sounds are refracted downwards where they are reflected by the surface of the water and continue to move in a sonic channel close to the surface. It is for this reason that even low intensity sounds carry for long distances over water surfaces at the end of a warm day.

The normally decreasing temperature gradient in the atmosphere ends at an altitude of about 15 km. Above this there is an inversion of the temperature gradient and an altitude may be reached at which the temperature is equal to or greater than that at the surface of the earth. In an atmosphere with such a temperature gradient the path of a sound wave from a source on the earth's surface will be refracted upwards, until it reaches the inversed temperature gradient. The sound will then be deflected downwards and may be totally refracted so that it returns to the earth's surface. This process is illus-

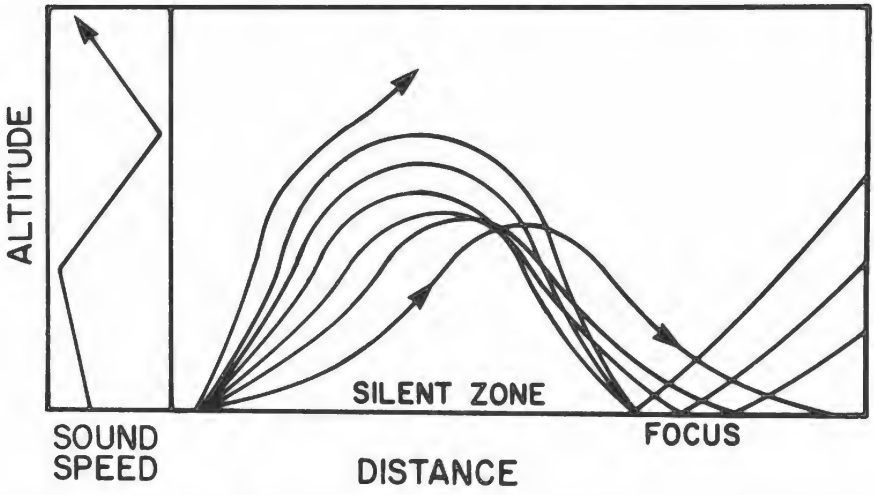


Figure 1. The variation of sound speed with altitude causes the sound from a localized source to travel along paths which produce a zone of silence and a region of focussing.

trated in Figure 1. It can be shown that sound waves leaving a source at grazing incidence along the surface of the earth will be totally refracted if the inverse temperature gradient results in a sound speed which is equal to that on the earth's surface. Sound which starts off from the source at higher angles of elevation will also be returned to the earth if there are levels in the atmosphere at which the temperature is greater than that on the surface.

This phenomenon therefore produces a zone of silence around the source, outside of which the sound will be heard and may be intense as a result of the focussing of rays from a localized source. The returning sound will be reflected from the ground with little loss of energy, and the refraction process may be repeated a number of times, thus carrying the sound to even greater distances.

#### Sound Distribution from Mt. St. Helens

The only way of determining the sound distribution over an area of many thousand square kilometers is to seek reports from the general public. This was done by sending a letter to the editor of every newspaper published within about 300 km of Mt. St. Helens. The letter requested readers to describe what they had heard on the morning of the eruption and to compare the intensity of the sound with that of distant thunder, a slamming door, quarry blasting, or the sound of an artillary piece being fired. The response to this request was overwhelming in that over 4,000 letters were received during the next few weeks, in addition to hundreds of telephone calls. The location of each report was plotted together with an estimate of the sound intensity on a scale of three, namely very loud, loud, or audible. This plot produced a clear picture of the classical zone of silence, as shown in Figure 2.

The closest location to the mountain at which sound was heard was 100 km away

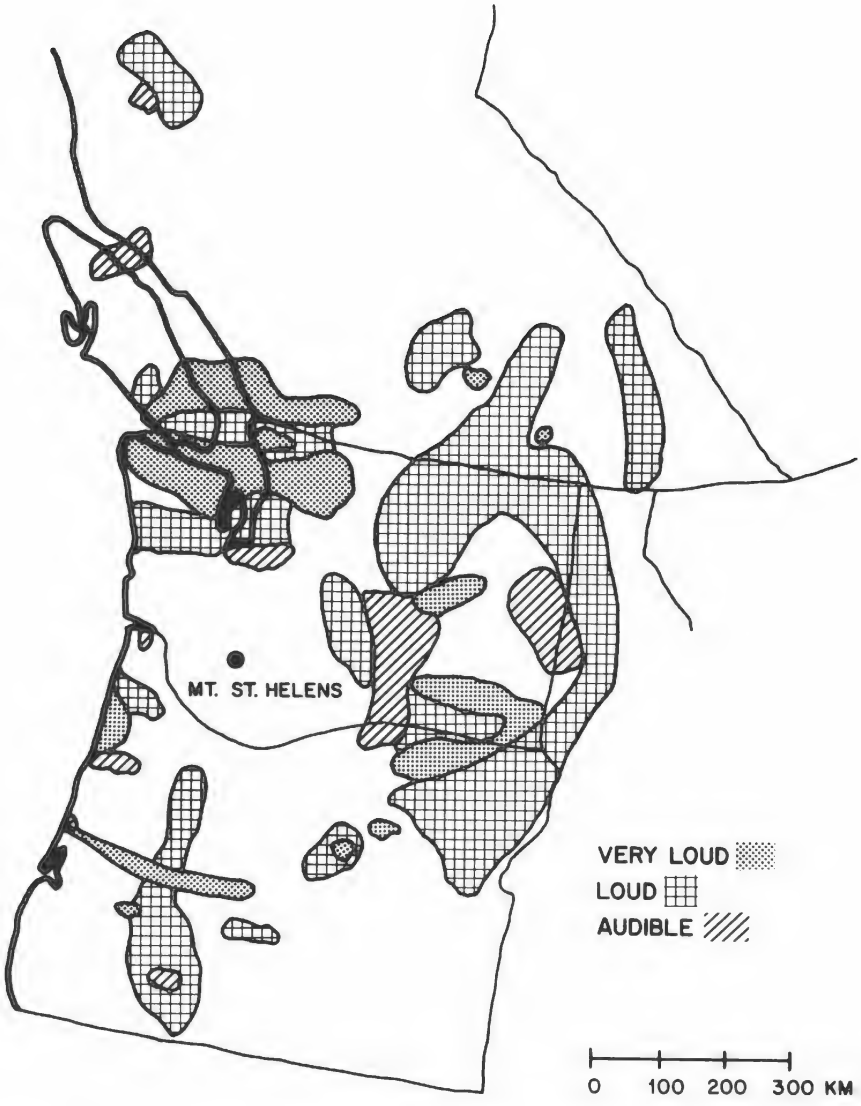


Figure 2. The distribution of sound from Mt. St. Helens based on the reports of over 4000 observers.

and all the reports from this distance described a low intensity sound. At greater distances from the mountain the sound intensity increased, and seems to have reached a maximum between 250 and 300 km from the mountain. At still greater distances the sound intensity decreased and the greatest distance from the mountain from which reports were received was about 930 km. The sound may have reached greater distances but reports were not filed because observers did not know of the survey. One report

which appeared reliable in terms of the type of sound heard and the time of arrival, was received from Maple Creek in South Saskatchewan about 1115 km from Mt. St. Helens, but a request over local radio stations did not bring forth any other reports from that area. It is not unreasonable to assume that the sound could have reached such distances either as a result of multiple reflection, or by a refraction at even higher altitudes in the ionosphere.

The plot of the areas with similar intensities shows a consistent picture with the regions of greatest intensity at about the same distance from the mountain in all directions. Conclusions should not be drawn from the size of the areas from which the reports were received because of considerable variations in population densities. The region which lies due north of the mountain, from which most of the reports were received, has the greatest population density including the cities of Seattle, Tacoma, Bellingham, Vancouver, and Victoria. In contrast, the area to the southeast of the mountain at about the same distance has very few population centers so that few reports were to be expected, but those that were received described the sound in a similar manner to the reports from the north. The zone of silence within a radius of about 100 km cannot be explained in terms of population density since it includes large cities such as Portland, Oregon which is 80 km from the mountain, and from which no reports were received.

Observers reported many other features about the sound, in addition to their descriptions of the intensity. The most common report was of the number of bangs which were heard. Most of the closest observers reported only a single event. At slightly greater distances most reports described two or three bangs, and in the region of the most intense sound at least four, and as many as fifteen independent bangs were reported. The report of the fifteen events was made by a geophysicist who is known to be an accurate and careful observer.

Some of the individual sounds were undoubtedly produced by local reflections from hills and buildings, but there is little doubt that there were several sound arrivals from the mountain. CFAX radio station in Victoria was broadcasting live at the time of the eruption and a recording was obtained of four separate explosion-like sounds of sufficient intensity to be heard within the studio. The intervals between the successive sounds were 3 seconds, 5.8 seconds, and 3.5 seconds. It is interesting to note that many observers described the intervals between the bangs to be much longer than those actually recorded.

There were many reports of animal reactions to the event, the animals frequently reacting before the sound was heard. Several observers reported they were alerted to the event by the cessation of bird sounds. There were also many reports of the reaction of dogs before the sound was heard. This author noted that his dog began to run wildly around the garden barking vociferously shortly before the first bangs were heard. There were numerous reports from people whose window panes were deflected by the pressure and the pulses were long enough to produce an air flow which disturbed curtains, and could be felt as it blew through the hair of people standing by an open window.

It is surprising that there were no reports of structural damage, other than that caused by objects falling from shelves. The author has had considerable experience with shock waves from large scale explosions and expected that some damage to windows and plaster walls would have been produced by the intensity of the sound which reached Victoria.

#### Atmospheric Temperature with Wind Profiles

The path of a sound ray in the atmosphere is determined by the gradient of the sound signal velocity, where the signal velocity is defined as the sound speed of the air plus the wind velocity. The sound speed of gas is primarily a function of the temperature, namely it is proportional to the square root of the absolute temperature. Winds in the upper atmosphere, particularly when jet streams are present, can have significant effects on the sound signal velocity gradient, but this does not appear to have been the case on the morning of 18 May 1980.

The temperature gradient in the lower 10 km of the atmosphere normally decreases linearly with altitude. There is then a region of constant temperature to an altitude of about 25 km, after which a temperature inversion occurs and the temperature increases steadily to an altitude of over 50 km. This variation of temperature with altitude is shown in Figure 3 as the solid curve, which is the International Civil Aviation Organization Standard Atmosphere (Handbook of Chemistry and Physics 1981). The actual temperatures and wind speeds in the atmosphere are measured several times a day by means of radiosonde balloons. Data were obtained from three such balloon ascents in the region of Mt. St. Helens a few hours before the major eruption. The closest ascent to the mountain was off the Washington coast but this ascent terminated at 15.9 km. The balloon ascents at Port Hardy and Vernon, B.C., continued to altitudes of 32 km before the balloons burst. The temperature data from these three ascents are plotted in Figure 3. It can be seen that the three temperature profiles were very similar to each other and to the International Standard.

The Port Hardy temperature profile has been converted to sound speed and is plotted in Figure 4. The observed wind velocity vectors have been added to the sound speed and the resulting sound signal profiles for five directions are plotted in Figure 5. The wind velocity is seen to have produced small, local inversions in the signal speed gradients to the south and southeast at an altitude of about 10 km, but they are unlikely to have had a significant effect on the sound transmission. At altitudes higher than 30 km the wind speeds were very low, about 2 m $s^{-1}$.

These results clearly show that atmospheric conditions on the morning of 18 May 1980 were appropriate for the refraction of sound from the stratosphere, but that no returns of sound from altitudes less than 30 km would have been expected, and wind velocities were such that azimuthal variation was of secondary importance. The theory of sound transmission in a stratified atmosphere as described by Cox *et al.* (1954), Cox (1958), Gilbert (1962), and Thompson (1971) shows that in order for sound from a source on or near the surface of the earth to be totally refracted, the sound speed and wind gradients must be such that a signal speed is reached equal to that at the altitude of the source. From the gradients shown in Figure 3 it is clear that this condition would have been attained at an altitude of about 50 km.

#### Barograph Results

Most of the data about the intensity and time of arrival of the sound from Mt. St. Helens consists of subjective reports from a large number of observers. The only quantitative data were obtained from continuously recording barographs. These instruments measure slow changes of atmospheric pressure and do not give an accurate measurement of the magnitude or the time of arrival of a relatively short pulse or a series of pulses such

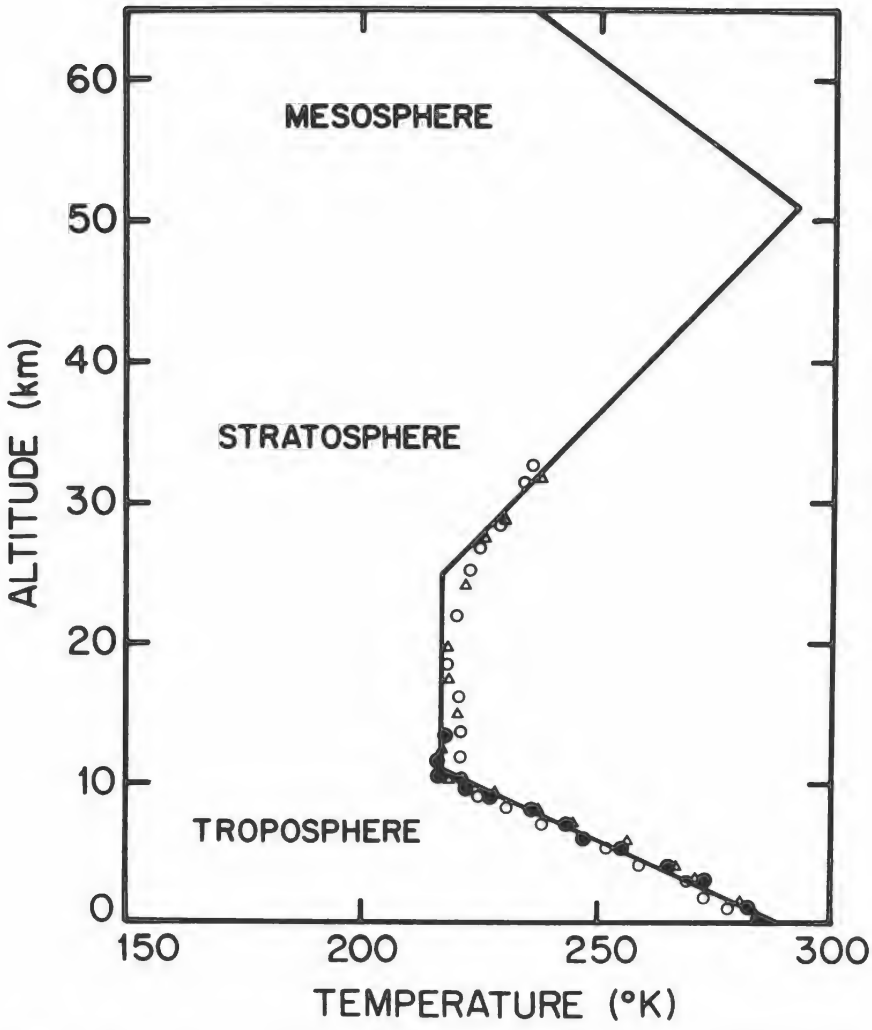


Figure 3. Variation of temperature with altitude. The solid curve is the International Civil Aviation Organization Standard. The points are values measured by balloon ascents in the early morning of 18 May 1980: • Washington coast; ° Port Hardy; △ Vernon, B.C.

as those discussed here. The time resolution of these instruments was considered to be not better than five minutes, and the times of arrival of the pressure pulses recorded by barographs, to the nearest five minuts, are mapped in Figure 6 The distances from Mt. St. Helens of these barograph stations are plotted versus the corresponding times of arrival in Figure 7. It was not possible to detect any consistent azimuthal variations in these results, and the scatter of the points is probably caused by the poor time resolution of the instruments. The points have been fitted by least squares to a straight line, plotted in Figure 7, with a slope corresponding to a speed of 238 m $s^{-1}$. This is

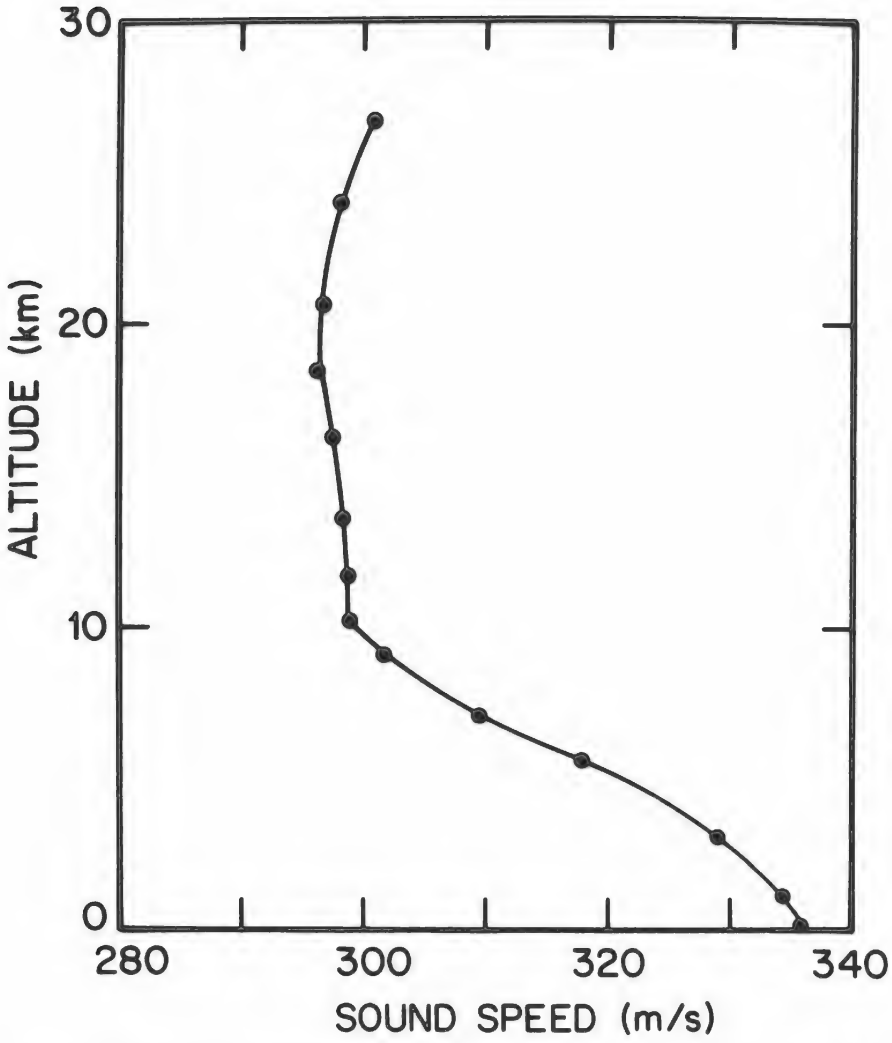


Figure 4. Variation of sound speed with altitude calculated from the temperatures measured on a balloon ascent from Port Hardy, B.C. on the morning of 18 May 1980.

clearly less than the speed of a direct sound wave along the earth's surface, of 336 m $s^{-1}$. The line representing this speed is also plotted. It was a similar difference in velocity which, when first observed at the beginning of the century, lead to the hypothesis of the upper atmospheric transmission of sound from intense sources.

Using the atmospheric temperature gradients plotted in Figure 3, and the theory of sound propagation in the atmosphere as presented by Cox (1958), the path of any sound ray originating from Mt. St. Helens can be calculated. This has been done for a ray leaving the source horizontally, and the path is shown as Figure 8. Initially the ray has a circular trajectory with a radius of curvature of 78 km to an altitude of 11

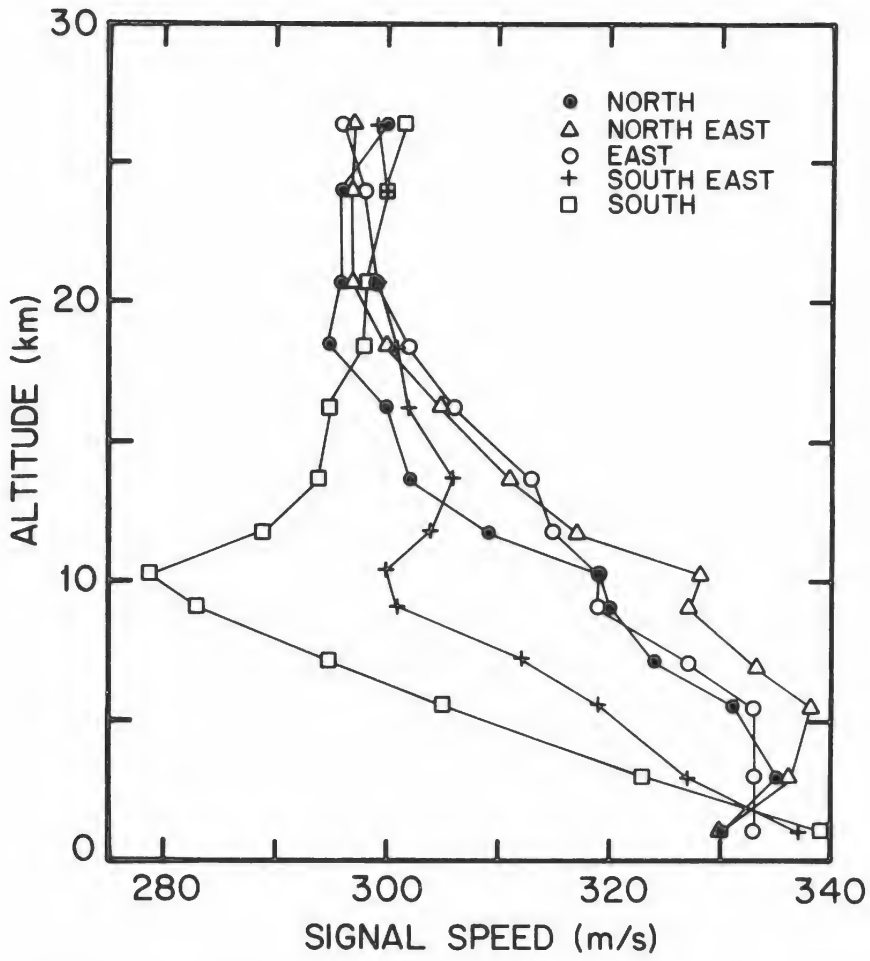


Figure 5. Variation of sound signal speed with altitude, calculated for various azimuths using the temperatures and wind velocities measured on a balloon ascent from Port Hardy, B.C.

km, and with a path length of 42 km. It then moves in a straight line for 27 km at an inclination of 31.2°. At an altitude of 25 km it encounters a reversed temperature gradient and follows another circular trajectory with a radius of curvature of 174 km, and a path length of 95 km to the point at which it is again horizontal at an altitude of 50 km. A symmetrical path returns the ray to the surface of the earth at a distance of 304 km, with an arrival time of 17.4 min. This point has been plotted in Figure 7, and is seen to be close to the line representing the observed times of arrival.

A similar calculation show that all the sound rays leaving the volcano at angles of elevation between 15° and 20° might have been expected to return to earth at about the same horizontal distance of 280 km and at the same time of 16 min. This local

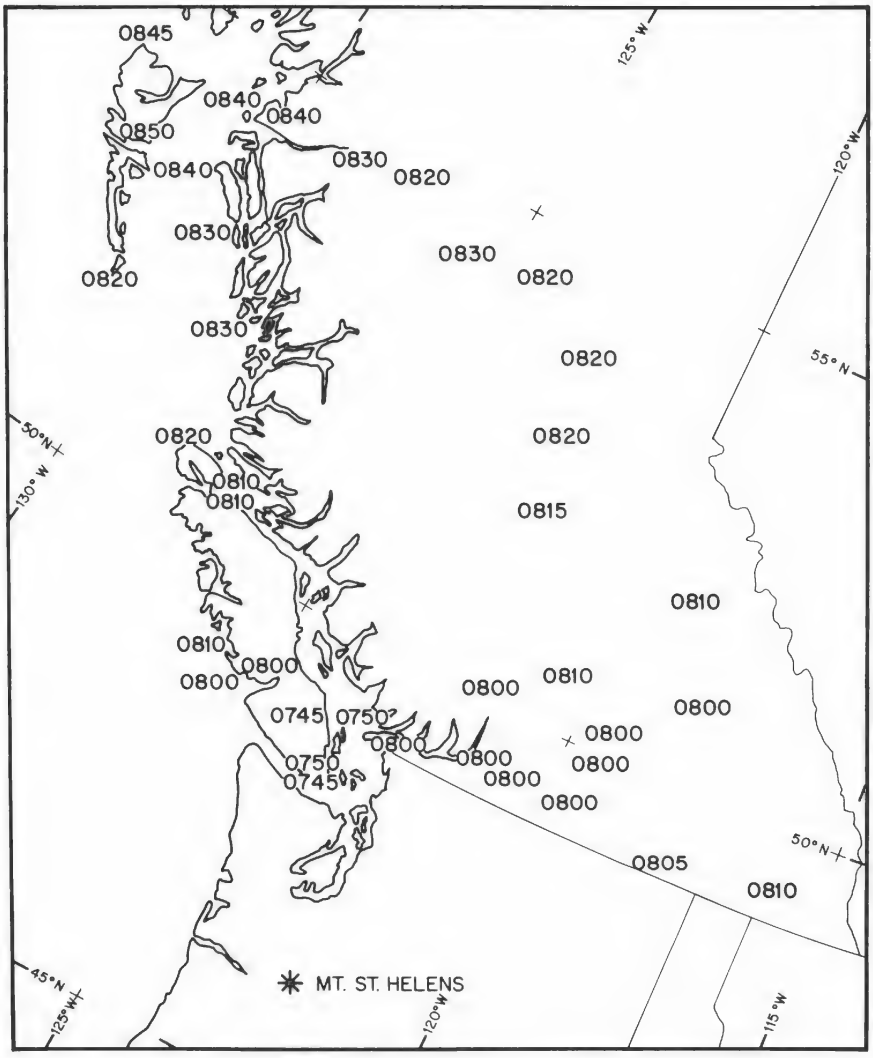


Figure 6. Times of arrival (P.D.T.) of the pressure pulse from Mt. St. Helens recorded by barographs, to the nearest five minutes.

front has also been plotted in Figure 7 and is close to the distance at which the most intense sound was reported in all azimuthal directions.

The sound ray with an initial angle of elevation of 20° would have become horizontal at an altitude of about 51.9 km which was probably the upper limit of the positive temperature gradient. Rays leaving the volcano at higher angles of elevation would therefore not be expected to have returned to earth.

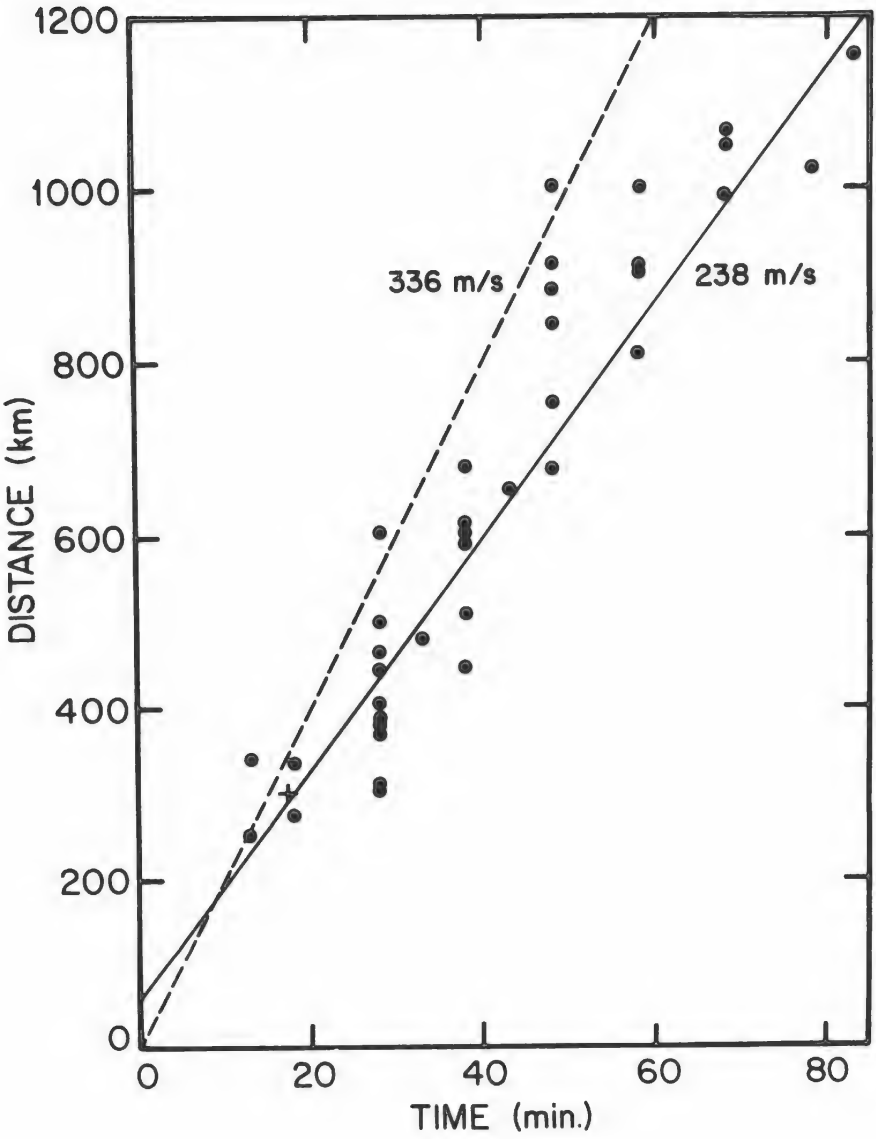


Figure 7. Time of arrival of the pressure pulse versus distance from Mt. St. Helens. The solid points are the barograph data and the solid line the least squares straight line fit to those points. The dashed line shows the expected arrival times for a pulse travelling close to the surface of the earth at a speed of 336 m · $s^{-1}$. The cross is the time of arrival calculated for a sound ray leaving Mt. St. Helens horizontally and being refracted through the upper atmosphere.

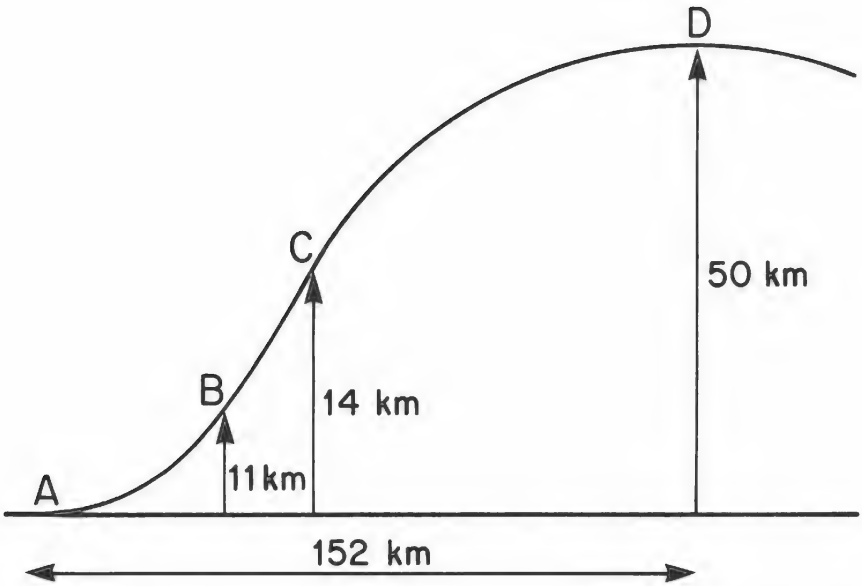


Figure 8. Path of a sound ray leaving Mt. St. Helens horizontally, calculated using the international temperature profile plotted in Figure 3. From A to B the radius of curvature is 78 km; from B to C the path is a straight line and from C to D the radius of curvature is 174 km. The ray is totally refracted at an altitude of 50 km and a horizontal range of 152 km.

**Form of the Sound Pulses**

The detection by the human ear of a pressure pulse from a source such as Mt. St. Helens or a large explosion, depends on the frequency components in the pulse. A pulse which is very long in duration, may not be heard even though of large magnitude, but will be detected by an instrument such as a barograph. Normal sound waves are trains of small amplitude pressure pulses which retain their frequency content with little change when transmitted over long distances. It is for this reason that listeners at the front and the back of a concert hall hear music which is qualitatively the same, differing only in amplitude. The conditions for such an acoustic wave are that both the amplitude and the gradient of the pressure within the wave be small. When both of these conditions are not met the gradient of the leading edge of a pressure pulse will increase, changing the frequency content of the wave which may eventually develop into a shock wave with a virtual instantaneous change in the physical properties of the gas at the leading edge. This steepening effect will be enhanced if the wave travels through a region with a negative temperature gradient in which the leading part of the wave travels in a gas with a lower speed of sound than the rest of the wave. It should be stressed that in a uniform atmosphere, changes in the profile of a pressure pulse are determined by the magnitude of the pressure gradient, so that large amplitude waves can travel with little change in shape if they are sufficiently long.

The major eruption of Mt. St. Helens was not a fast moving event when compared to a large chemical or nuclear explosion. There have been several estimates of the

energy yield of the eruption. The one most pertinent to the discussion here is based on the magnitude of the pressure pulse reaching large distances, and this gives a value for the initial eruption of a few, but probably not more than 10 Mt TNT equivalent (Reed 1983b). A series of excellent photographs of the initial eruption was obtained from a small airplane which was flying only a few hundred meters from the mountain. The pilot did not feel or hear the pressure pulse. A detailed inspection of the region near the mountain, immediately adjacent to the so-called blow-down area in which the forest was destroyed, showed no evidence of a shock wave. The damage to the forest was caused by a jet of hot gas and ash, and although flow velocities within this jet may have been supersonic with respect to the materials in the jet (Sturtevant and Kieffer 1983), they appear to have been subsonic with respect to the atmosphere. Flow speeds within the jet have been estimated at 60 m $s^{-1}$, as compared with the speed of sound in air at N.T.P. of approximately 340 m $s^{-1}$.

The pressure pulse recorded by a barograph at Toledo Airport, 54 km from the mountain and within the zone of silence, had a rise time longer than 1.3 s, a peak pressure of 373 Pa, and a 13 minute negative phase, when the pressure was reduced below atmospheric due to the suction of the rising hot gases. In contrast to this slow rising pulse, the sounds which arrived at distances of over 150 km had changed their form during transmission through the stratosphere and had the characteristics of long duration shock waves.

Although some of the sound repetition may have been caused by local reflections, both the consistency of reports over large areas and the sound recordings indicate the arrival of at least four separate shock-like pulses. The multiple pulses could have arisen from separate blasts from the mountain, but there is no evidence of this in the photographs of the initial eruption. Alternatively there may have been multiple reflections in the stratosphere, but again there is no evidence from the data obtained by the balloon ascents of any variations in the stratospheric temperature and wind profile which would account for the multiple arrivals.

#### Conclusions

Reports from over 4000 observers in the region surrounding Mt. St. Helens clearly demonstrated a zone of silence extending to 100 km from the eruption. Beyond that distance sounds originating from the volcano where heard to a distance of over 900 km, with the loudest sounds between 250 and 300 km. This phenomenon was caused by the refraction of the sound in the stratosphere as a result of the temperature gradient inversion which started at an altitude of about 25 km, with the temperature at 50 km equalling that at the ground surface. The times of arrival of the sound recorded at barograph stations confirmed a total refraction of the sound at that altitude. The pressure pulse originating at the mountain appears to have been slow rising and of long durationtion, but it steepened into a series of shock waves during its tranmission through the atmosphere. Most observers reported several sound arrivals, separated by a few seconds, and it is not clear if this separation was a feature of the eruption or due to stratifications in the atmosphere.

#### Acknowledgments

The author gratefully acknowledges the assistance of the many people who provided

the data for this study. These include the several thousand observers who responded, many at length and with valuable detail, to the request for information on the sound of the eruption. The large number of people involved precluded the sending of individual letters of thanks. Newspapers, and radio and television stations throughout the region were enthusiastic in their publicity of the project. The assistance of CFAX radio station in Victoria, which provided a tape recording of the sounds reaching that city, is particularly acknowledged. The atmospheric temperatures and wind velocities, and the times of sound arrival at barograph stations were generously provided by the Pacific Region Atmospheric Environment Service of Canada. The data for this project were tabulated and plotted by Mr. Graham Carlow.

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# Winter Distribution of Bald Eagles Along a Segment of the Boise River, Idaho

## Abstract

Bald Eagles (*Haliaeetus leucocephalus*) were observed from mid-December 1982 through mid-March 1983 to determine their winter density and distribution along the Boise River extending 14 km upstream from Boise, Ada County, Idaho. A minimum of 10 individual eagles were observed a total of 148 times. Early in the winter, eagles were rather evenly distributed along the 14 km stretch of river. Thereafter, 60 percent of the sightings were within the first kilometer of river below Lucky Peak reservoir.

## Introduction

The Boise River, upstream from Boise, Ada County, Idaho, provides the requirements of open water, suitable habitat, and adequate prey for Bald Eagles wintering in the western United States (Steenhof *et al.* 1980), and is annually used by eagles for 3 or more months each winter (Jensen 1981). Ownership of the land adjacent to the stretch of river from Boise to Lucky Peak Dam (Figure 1) is a mosaic of private, industrial, and state interests. The development of the bottomland within the floodplain is under the supervision of the U.S. Army Corps of Engineers. Currently there is only limited human activity in this area. Nearly 75 percent of the land adjacent to the river is either undisturbed or is pastureland. However, several plans for development of sites along this segment of the river have been proposed. Proposals range in scope from high density housing tracts to parks with little or no anticipated habitat changes. This mixture of land ownership and planning for development, coupled with the endangered species status of the Bald Eagle (USDI 1978), and Jensen's (1981) unpublished data on wintering eagles, prompted this study. Our objectives were to quantify the temporal and spatial density changes of the wintering eagle population, and to identify specific habitat use areas and possible roost sites.

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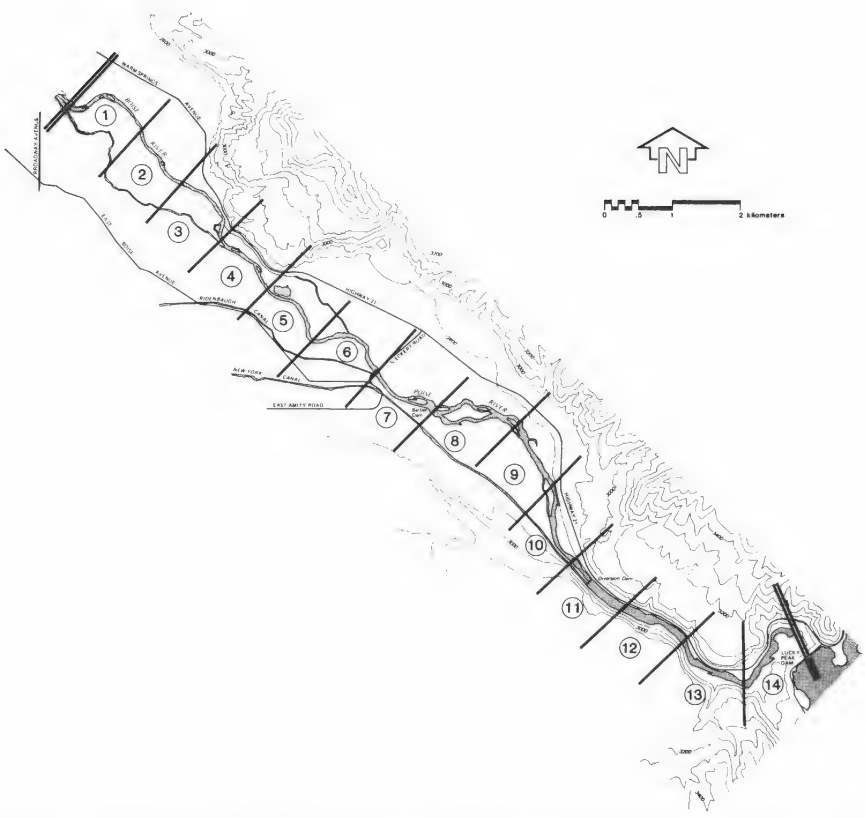


Figure 1. Location of the 1982-83 wintering Bald Eagle study area along the Boise River, Ada County, Idaho.

### Study Area

The study area extended 14 km upstream from Walnut Street in Boise to Lucky Peak Dam (Figure 1). The lower 7 km of the river, from Walnut Street to Barber Dam, is relatively shallow and fast flowing, bordered by native riparian habitat interspersed with pastureland and residential, corporate, and municipal developments. Extending approximately 3.5 km upstream from Barber Dam to Diversion Dam the river is braided, slow flowing, and known locally as Barber Pool. Several islands in this area, and the adjacent river banks, support stands of mature cottonwoods (*Populus* sp.). Immediately above Diversion Dam the river valley abruptly narrows to a 45 m deep canyon which extends upstream to Lucky Peak Dam. With the exception of the discharge basin immediately below the dam, this upper 3.5 km reach of the river is mostly slack water.

### Materials and Methods

Surveys for Bald Eagles were conducted every third day from 13 December 1982 through 19 March 1983. Morning and afternoon surveys, starting at dawn and three hours prior

to dark, respectively, were conducted on alternate sampling days. Three types of surveys were conducted because no single method provided complete coverage of the study area:

1) a vehicle survey route along Highway 21 (Figure 1) which paralleled the study area; 2) stationary observations from north of the river between km 3 and 4 (Figure 1), and from the bluffs south of the river overlooking Diversion Dam in km 11; 3) float trips by canoe.

Each survey lasted 2-3 hours. Observations from the bluffs above Diversion Dam were conducted every fourth sampling day. Canoe trips were taken at 3-4 week intervals. Data recorded for each eagle sighted included the location, habitat, time, activity (perching, feeding, soaring or flying), and the age (adult or immature).

#### Results

During the 31 surveys (21 by vehicle, seven stationary observations, and three canoe floats) a total of 148 sightings of Bald Eagles was recorded. The maximum number of eagles observed simultaneously, hence the minimum known to use the study area, was 10. This occurred on 29 January and 18 February. Four of the birds observed on 29 January were identified as adults, and 6 as immature. Of the 148 total sightings, fifty-one (34 percent) were of adult birds, 62 (42 percent) were of immatures, and 35 (24 percent) were of unknown age.

Temporal and spatial use of the river environs by eagles was not uniform (Table 1). Eagles were observed along the lower 3 km of the study area only during the first two weeks of the study, and then only in very limited numbers. Eagles seemed to prefer the Barber Pool area (specifically river segment 8 and 9; Figure 1) during late December and early January. Thereafter, the majority of the eagle sightings occurred directly below Luck Peak Dam in river segment 14 where no eagles were recorded during the first month of the study. The sightings in the Barber Pool area were equally divided between perching and flying birds. Immediately below Lucky Peak Dam, over 90 percent of the eagles observed were airborne, either soaring over the cliffs or circling low over the water. The maximum number of eagle observations occurred during late January and early February. By mid-March a minimum of four Bald Eagles were observed between Diversion and Lucky Peak Dams.

Jensen (1981) reported that Bald Eagles used the islands in Barber Pool as night

TABLE 1. Number of observations of Bald Eagles along each 1 km segment of the Boise River, Idaho, study area, during the 1982-1983 winter.

| Dates | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | Two Week Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11-25 Dec. | 0 | 1 | 1 | 1 | 2 | 1 | 0 | 2 | 3 | 4 | 2 | 2 | 1 | 0 | 20 |
| 11-25 Dec. | 0 | 1 | 1 | 1 | 2 | 2 | 0 | 2 | 3 | 4 | 2 | 2 | 1 | 0 | 20 |
| 26 Dec.-8 Jan. | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 10 | 5 | 1 | 0 | 1 | 1 | 0 | 21 |
| 9-22 Jan. | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 4 | 3 | 1 | 5 | 0 | 2 | 10 | 29 |
| 23 Jan.-5 Feb. | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 2 | 3 | 0 | 1 | 1 | 1 | 22 | 33 |
| 6-9 Feb. | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 3 | 1 | 0 | 0 | 1 | 1 | 20 | 28 |
| 20 Feb.-5 Mar. | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 9 | 12 |
| 6-19 Mar. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 3 | 5 |
| Total per segment | 0 | 1 | 1 | 5 | 5 | 3 | 5 | 21 | 15 | 6 | 9 | 6 | 7 | 64 | Grand Total 148 |

roost sites during winter. From the onset of this study until 14 January we regularly recorded eagles perched in the cottonwood trees overlooking the river at Barber Pool during the day, as well as at both sunrise and sunset. Sunset and sunrise observations imply that eagles roosted at Barber Pool. After mid-January, when the maximum eagle activity shifted to the upper reaches of the study area, eagles were consistently observed soaring over the foothills on the north side of the river late each afternoon. Rather than moving downriver toward Barber Pool to roost, these birds would fly in a northerly direction. Although we did not determine the specific night roost area, the birds appeared to roost in the coniferous forests near Schoonover Gulch or the Robie Creek drainage 10-12 km due north of Luck Peak Dam.

#### Discussion and Conclusions

The population of Bald Eagles wintering along the Boise River is unusual because of its proximity to a metropolitan area. The minimum of 10 eagles we observed is similar to the maximum of 12 reported by Jensen (1981) overwintering in the same area two years prior to this study. Although this 14 km segment of the Boise River appears to support 10 or more Bald Eagles during the winter, it is not known exactly how many eagles consistently use the area. The Lucky Peak Reservoir, directly upstream from our study area, and Arrowrock Reservoir above that, both support wintering populations of Bald Eagles. A regular exchange of birds between these areas is quite possible.

Until late January, Barber Pool apparently provided a good area for hunting and day perching, and quite possibly served as a night roost. After mid-winter eagles were observed more frequently in the upper stretch of the study area, and began using a night roost 10-12 km distant from and the river. This trend continued until the end of the study when eagles were leaving their wintering habitat.

The reason for the apparent change in night roosts is unknown, but daily movements of this sort are not particularly novel for eagles. Bald Eagles wintering near the American Falls Reservoir in southeastern Idaho make daily moves in excess of 15 km to and from a roost in the Bannock Mountain Range (C. H. Trost, Biology Dept., Idaho State University, personal communication). Similar movements were reported by Swisher (1964) for a population of eagles in northern Utah.

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# Fire on the Early Western Landscape: An Annotated Record of Wildland Fires 1776-1900

## Abstract

Scientific and historical literature was searched for documented accounts of early fires in the "interior West"—Montana, Wyoming, Idaho, Utah, Nevada, and eastern Oregon. One hundred and forty-five accounts of fires by 44 observers were found. The majority of accounts described fires in progress. A smaller proportion referred to burned areas that were encountered; a few simply described regional fire occurrence based on the journalists' observations. Indians were identified as the primary ignition source over wide areas at lower and middle elevations. Some journalists noted that fire enhanced grasses and inhibited growth of woody plants.

The historical record, and fire history based on analysis of fire scars demonstrate that fire was a major perturbation in the interior West. Such knowledge can help resource managers understand subsequent vegetative changes, and can enable them to use prescribed fires intelligently.

## Introduction

Various researchers in western North America have concluded that wildfire was a major perturbation before the turn of the century (Stewart 1951, Pyne 1982). This knowledge is important for managing forest and rangelands, for interpreting successional patterns of early-day vegetation, for understanding successional changes that have taken place in modern times, and ultimately for managing forests and rangelands. Vegetational changes, after all, have major implications for management of wildlife, timber, and other resources.

Researchers in various disciplines have cited historical literature that describes early fires in the interior West. Only a few, however, have used these sources to interpret fire's past role in various ecosystems (Moore 1972, Shinn 1980, Barrett 1981). These previous studies provide insight on early fire occurrence in parts of the interior West, but over large areas there was little knowledge of historical fire occurrence. Therefore, a broader search of western literature prior to 1900 was conducted. This paper summarizes and interprets accounts of fire pertaining to a large area of the interior West, including Montana, Wyoming, Idaho, Utah, Nevada, and eastern Oregon.

## Methods

Early journals were located and all accounts of early-day fires were recorded. A detailed search was also made through diverse and obscure literature covering the activities of fur trappers, explorers, government surveyors, natualists, emigants, military expeditions, miners, and others. This search turned up other references on fire that had not

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been previously reported in the scientific literature. Each narrative was examined and the observer's name, date, and approximate location was recorded. Categories were then developed to aid ecological interpretations about past fire occurrence and effects. These categories included whether the citation described a fire in progress or denoted evidence of past burning, relative size of burn, duration of burning, and ignition source. To the extent possible, fire characteristics, and the direct or indirect effects of fire on vegetation, people, wildlife, and stock were also categorized.

### Results and Discussion

The literature search resulted in 145 accounts of fires documented by 44 observers from 1776-1900 (Table 1). Most accounts described fires in progress. Others referred to burned areas that were encountered, while a few simply described regional fire occurrence based on the journalists' observations.

TABLE 1. Listing of fires by state, description, and ignition source (see legend at end of table).

| Map No. (Fig. 1) | Observer | Reference | Date | Location | Description[1] IP | WY | HD |
|---|---|---|---|---|---|---|---|
| Montana | | | | | | | |
| 1 | Lewis | Thwaites 1959 | 7-20-1805 | Hauser Lake | | I | |
| 2 | Clark | Thwaites 1959 | 7-25-1805 | Three Forks | | I | |
| 3 | Lewis | Thwaites 1959 | 8-4-1805 | Big Hole R. | | I | |
| 4 | Lewis | Thwaites 1959 | 8-15-1805 | Horse Prairie | | I | |
| 5 | Lewis | Thwaites 1959 | 8-23-1805 | Clark Canyon Reser. | | | I |
| 6 | Larocque | Hazlitt 1962 | 9-25-1805 | Glendive | U | | |
| 7 | Clark | Thwaites 1959 | 7-6-1806 | Big Hole | | | U |
| 8 | Clark | Thwaites 1959 | 7-19-1806 | Yellowstone R. | U | | |
| 9 | Clark | Thwaites 1959 | 7-30-1806 | Miles City | | U | |
| 10 | Ferris | Phillips 1940 | 9-1-1831 | Big Hole | I | | |
| 11 | Ferris | Phillips 1940 | 9-2-1831 | Pioneer Mtns. | I | | |
| 12 | Catlin | Catlin 1891 | 1832 | Northeastern Mont. | | | U |
| 13 | Denig | Ewers 1961 | 1833 | Northeastern Mont. | | | I |
| 14 | Maximilian | Thwaites 1966c | 1833 | Northeastern Mont. | | | I |
| 15 | Ferris | Phillips 1940 | 8-13-1833 | Bitterroot R. | I | | |
| 16 | Maximilian | Thwaites 1966c | 9-2-1833 | Missouri R. | | I | |
| 17 | Maximilian | Thwaites 1966c | 10-30-1833 | Missouri R. | | N | |
| 18 | Russell | Haines, A. 1965 | 9-10-1835 | Hebgen L. | I | | |
| 19 | Kurz | Hewitt 1969 | 1851 | Northeastern Mont. | | | I |
| 20 | Kurz | Hewitt 1969 | 11-15-1851 | Northeastern Mont. | | | I |
| 21 | Stevens | Stevens 1855 | 8-29-1853 | Milk Cr. | N | | |
| 22 | Mullan | Mullan 1855a | 9-25-1853 | Little Blackfoot R. | | U | |
| 23 | Mullan | Mullan 1855b | 12-30-1853 | Bighole R. | | I | |
| 24 | Mullan | Mullan 1855b | 12-31-1853 | Divide | | I | |
| 25 | Raynolds | Raynolds 1868 | 8-14-1859 | Wolf Mountains | I | | |
| 26 | Mullan | Mullan 1863 | 8-24-1859 | Coeur d'Alene Mtns. | U | | |
| 27 | Mullan | Mullan 1863 | 8-26-1859 | Clark Fork | U | | |
| 28 | Mullan | Mullan 1863 | 8-27-1859 | Clark Fork | U | | |
| 29 | Mullan | Mullan 1863 | 8-28-1859 | Clark Fork | U | | |
| 30 | Raynolds | Raynolds 1868 | 9-9-1859 | Soap Cr. | | I | |
| 31 | Raynolds | Raynolds 1868 | 9-10-1859 | Little Horn R. | | U | |
| 32 | Raynolds | Raynolds 1868 | 9-12-1859 | Wolf Mtns. | | U | |
| 33 | Mullan | Mullan 1861 | 3-10-1860 | Bitterroot R. | | I | |
| 34 | Stuart, G. | Phillips 1957 | 7-22-1861 | Clark Fork R. | I | | |
| 35 | Stuart, G. | Phillips 1957 | 7-29-1861 | Clark Fork | U | | |
| 36 | Stuart, G. | Phillips 1957 | 7-31-1861 | Clark Fork | U | | |
| 37 | Stuart, G. | Phillips 1957 | 8-14-1861 | Clark Fork | U | | |
| 38 | Stuart G. | Phillips 1957 | 9-5-1861 | Clark Fork | U | | |
| 39 | Stuart, J. | MT Hist. Soc. 1902b | 5-8-1863 | Hardin | U | | |
| 40 | Stuart, J. | MT Hist. Soc. 1902b | 5-16-1863 | Fort Smith | I | | |
| 41 | DeLacy | MT Hist. Soc. 1902a | 8-10-1863 | Centennial Mtns. | | U | |
| 42 | DeLacy | MT Hist. Soc. 1902a | 9-18-1863 | Gallatin R. | | | I |

TABLE 1. (Continued)

| Map No. (Fig. 1) | Observer | Reference | Date | Location | Description[1] IP | WY | HD |
|---|---|---|---|---|---|---|---|
| 43 | Cole | Hafen & Hafen 1961a | 8-31-1865 | Powder R. | I | | |
| 44 | Hayden | Hayden 1873 | 1872 | Gallatin R. | | U | |
| 45 | Havard | Havard 1878 | 1877 | Northeastern Montana | | | U |
| 46 | Stuart, G. | Phillips 1957 | 9-16-1881 | Judith Mountains | | | U |
| 47 | Stuart, G | Phillips 1957 | 1885 | Judith Mountains | | | U |
| 48 | Ayres | Ayres 1900 | late 1800s | Whitefish Range | | | U |
| 49 | Ayres | Ayres 1901 | late 1800s | Flathead Forest | | | U |
| 50 | Leiberg | Leiberg 1899a | late 1800s | Priest River | | | U |
| 51 | Leiberg | Leiberg 1899b | late 1800s | North Idaho | | | U |
| 52 | Leiberg | Leiberg 1899c | late 1800s | Bitterroot Mtns. | | | U |
| 53 | Leiberg | Leiberg 1904a | late 1800s | Little Belt Mtns. | | | I |
| 54 | Leiberg | Leiberg 1904b | late 1800s | Absaroka Range | | | U |
| Wyoming | | | | | | | |
| 1 | Fremont | Fremont 1887 | 8-19-1843 | Kemmerer | U | | |
| 2 | Fremont | Fremont 1887 | 8-20-1843 | Kemmerer | U | | |
| 3 | Stansbury | Stansbury 1852 | 9-21-1850 | Fort Steele | | | U |
| 4 | Raynolds | Raynolds 1868 | 5-17-1860 | Powder R. | | U | |
| 5 | DeLacy | MT Hist. Soc. 1902a | 8-19-1863 | Alpine | U | | |
| 6 | Palmer, H. | Hafen & Hafen 1961a | 8-6-1865 | Powder River | N | | |
| 7 | Palmer, H. | Hafen & Hafen 1961a | 8-11-1865 | Fort Reno | | I | |
| 8 | Bradley | Bradley 1873 | 1872 | Jackson Hole | | U | |
| 9 | Moran | Fryxell 1943 | 8-25-1879 | Teton Mtns. | U | | |
| 10 | Moran | Fryxell 1943 | 8-26-1879 | Teton Mtns. | U | | |
| 11 | Moran | Fryxell 1943 | 8-27-1879 | Teton Mtns. | U | | |
| 12 | Brandegee | Brandegee 1899 | 1897 | Yellowstone P. | | | U |
| Idaho | | | | | | | |
| 1 | Lewis | Thwaites 1959 | 8-30-1805 | Salmon R. | I | | |
| 2 | Lewis | Thwaites 1959 | 6-25 1806 | Lochsa R. | I | | |
| 3 | Stuart, R. | Rollins 1935 | 9-10-1812 | Soda Springs | | U | |
| 4 | Stuart, R. | Rollins 1935 | 9-13-1812 | Bear R. | I | | |
| 5 | Ross | Spaulding 1956 | 4-24-1824 | Lemhi Valley | N | | |
| 6 | Ogden | Rich 1950 | 4-15-1826 | Portneuf R. | I | | |
| 7 | Ogden | Rich 1950 | 4-16-1826 | Portneuf R. | N | | |
| 8 | Ogden | Rich 1950 | 4-27-1826 | Raft R. | I | | |
| 9 | Work | Haines, F. D. 1971 | 9-14-1830 | Boise | | U | |
| 10 | Work | Haines, F. D. 1971 | 9-15-1830 | Boise | | U | |
| 11 | Work | Haines, F. D. 1971 | 9-28-1830 | Magic Reservoir | U | | |
| 12 | Work | Haines, F. D. 1971 | 10-5-1830 | Magic Reservoir | | | U |
| 13 | Work | Haines, F. D. 1971 | 2-7-1831 | Snake R. | | I | |
| 14 | Ferris | Phillips 1940 | 8-19-1831 | Snake R. | I | | |
| 15 | Ferris | Phillips 1940 | 8-19-1831 | Lemhi Range | I | | |
| 16 | Work | Lewis & Phillips 1923 | 9-30-1831 | Musselshell Cr. | | U | |
| 17 | Work | Lewis & Phillips 1923 | 4-19-1832 | Lost R. | N | | |
| 18 | Townsend | Thwaites 1966a | 8-16-1833 | Wood R. | | I | |
| 19 | Wyeth | Young 1899 | 8-10-1834 | Mackay | I | | |
| 20 | Wyeth | Young 1899 | 8-17-1834 | Mountain Home | | I | |
| 21 | Russell | Haines, A. 1965 | 9-26-1834 | Pocatello | U | | |
| 22 | Wislizenus | Wislizenus 1912 | 8-14-1839 | Soda Springs | | I | |
| 23 | Bidwell | Kelly 1930 | 8-10-1841 | Soda Springs | U | | |
| 24 | Fremont | Fremont 1887 | 8-24-1843 | Cokeville | U | | |
| 25 | Fremont | Fremont 1887 | 8-25-1843 | Soda Springs | U | | |
| 26 | Fremont | Fremont 1887 | 8-26-1843 | Soda Springs | U | | |
| 27 | Fremont | Fremont 1887 | 10-6-1843 | Boise | | I | |
| 28 | Minto | OR Hist. Soc. 1901 | 9-6-1844 | Soda Springs | U | | |
| 29 | Minto | OR Hist. Soc. 1901 | 9-15-1844 | American Falls | | I | |
| 30 | Palmer, J. | Thwaites 1966b | 4-29-1846 | Boise | I | | |
| 31 | McKinstry | McKinstry 1975 | 7-26-1850 | Blackfoot | | U | |
| 32 | Mullan | Mullan 1863 | 8-22-1859 | Coeur d'Alene R. | U | | |
| 33 | Mullan | Mullan 1863 | 8-23-1859 | Coeur d'Alene R. | U | | |
| 34 | Stuart, J. | MT Hist. Soc. 1902b | 6-11-1863 | Bear R. | U | | |
| 35 | DeLacy | MT Hist. Soc. 1902a | 8-12-1863 | Centennial Mtns. | | U | |
| 36 | DeLacy | MT Hist. Soc. 1902a | 8-17-1863 | Palisades Reservoir | U | | |
| 37 | DeLacy | MT Hist. Soc. 1902a | 8-18-1863 | Palisades Reservoir | U | | |

TABLE 1. (Continued)

| Map No. (Fig. 1) | Observer | Reference | Date | Location | Description[1] IP | WY | HD |
|---|---|---|---|---|---|---|---|
| 38 | Leigh | Thomp. & Thomp. 1982 | 9-19-1875 | Kilgore | I | | |
| 39 | Leigh | Thomp. & Thomp. 1982 | 10-4-1875 | Snake R. | U | | |
| 40 | Leigh | Thomp. & Thomp. 1982 | 7-8-1876 | Teton Cr. | U | | |
| 41 | Leigh | Thomp. & Thomp. 1982 | 8-8-1878 | Upper Snake R. | N | | |
| 42 | Moran | Fryxell 1943 | 8-22-1879 | Idaho Falls | U | | |
| 43 | Moran | Fryxell 1943 | 8-23-1879 | Heise | U | | |
| Utah | | | | | | | |
| 1 | Escalante | Alter 1928 | 9-21-1776 | Spanish Fork | I | | |
| 2 | Escalante | Alter 1928 | 9-22-1776 | Spanish Fork | I | | |
| 3 | Russell | Haines, A. 1965 | 3-27-1841 | Salt Lake | | U | |
| 4 | Bidwell | Kelly 1930 | 8-17-1841 | Garland | I | | |
| 5 | Fremont | Fremont 1887 | 8-31-1843 | Tremonton | | | I |
| 6 | Stansbury | Stansbury 1852 | 8-26-1849 | Huntsville | I | | |
| 7 | Powell | Stegner 1962 | 1870 | Mtns. Statewide | | | I |
| 8 | Richards | WY Hist. Soc. 1931 | 7-23-1873 | Wasatch Mtns. | U | | |
| 9 | Richards | WY Hist. Soc. 1931 | 7-25-1873 | Wasatch Mtns. | U | | |
| Nevada | | | | | | | |
| 1 | Ogden | Rich 1950 | 5-15-1826 | Goose Creek | | U | |
| 2 | Ogden | Rich 1950 | 5-30-1826 | Bruneau R. | | U | |
| 3 | Ogden | Williams 1971 | 4-20-1829 | Independence Valley | I | | |
| 4 | Ogden | Williams 1971 | 6-7-1829 | Santa Rosa Mtns. | I | | |
| 5 | Bidwell | Kelly 1930 | 9-15-1841 | Pilot Range | U | | |
| 6 | Fremont | Fremont 1887 | 11-8-1844 | Reno | I | | |
| 7 | Bigler | UT Hist. Soc. 1932 | 8-5-1848 | Minden | I | | |
| Oregon | | | | | | | |
| 1 | Ogden | Davies 1961 | 9-24-1826 | Deschutes R. | U | | |
| 2 | Ogden | Davies 1961 | 9-26-1826 | Deschutes R. | | U | |
| 3 | Ogden | Davies 1961 | 10-4-1826 | Paulina | I | | |
| 4 | Ogden | Davies 1961 | 10-29-1826 | Malheur Lake | | U | |
| 5 | Ogden | Davies 1961 | 5-26-1827 | Warner Valley | | | I |
| 6 | Ogden | Davies 1961 | 6-22-1827 | Malheur Lake | | | I |
| 7 | Ogden | Davies 1961 | 7-14-1827 | Vale | I | | |
| 8 | Ogden | Davies 1961 | 9-21-1827 | Huntington | U | | |
| 9 | Ogden | Williams 1971 | 6-20-1829 | Malheur Lake | I | | |
| 10 | Work | Maloney 1945 | 9-29-1832 | Malheur Lake | I | | |
| 11 | Work | Maloney 1945 | 9-30-1832 | Malheur Lake | U | | |
| 12 | Work | Maloney 1945 | 10-1-1832 | Malheur Lake | | U | |
| 13 | Townsend | Thwaites 1966a | 9-1-1833 | LaGrande | I | | |
| 14 | Townsend | Thwaites 1966a | 9-3-1834 | Umatilla R. | I | | |
| 15 | Bonneville | Todd 1961 | 8-1834 | SE Oregon | I | | |
| 16 | Wyeth | Young 1899 | 9-1-1834 | Umatilla R. | | U | |
| 17 | Fremont | Fremont 1887 | 10-17-1843 | LaGrande | | U | |
| 18 | Fremont | Fremont 1887 | 10-23-1843 | Pendleton | | U | |
| 19 | Cross | Settle 1940 | 8-6-1849 | Blue Mtns. | U | | |
| 20 | Griffiths | Griffiths 1902 | 1900 | Burns | | I | |

[1] IP Fire in progress
WY Fire within past year
HD Historical documentation of fire
I Indian
N Non-Indian
U Unknown

Each fire's approximate location was plotted (Figure 1). Narratives lacking sufficient detail to plot fire location are listed in inset boxes within the appropriate state. Most of these are observations of smoke that could not be isolated to the approximate point of origin, or, are repeated observations over several days. A few are regional observations of recent and past fires. Though not mappable, these descriptions provide further perspective on the frequency, size, and effect on vegetation. The most explicit of these are Ayres (1900, 1901), Brandegee (1899), and Leiberg (1899a, 1899b, 1899c, 1904a, 1904b).

Most of the narratives of travels during summer and fall mention fires one or more

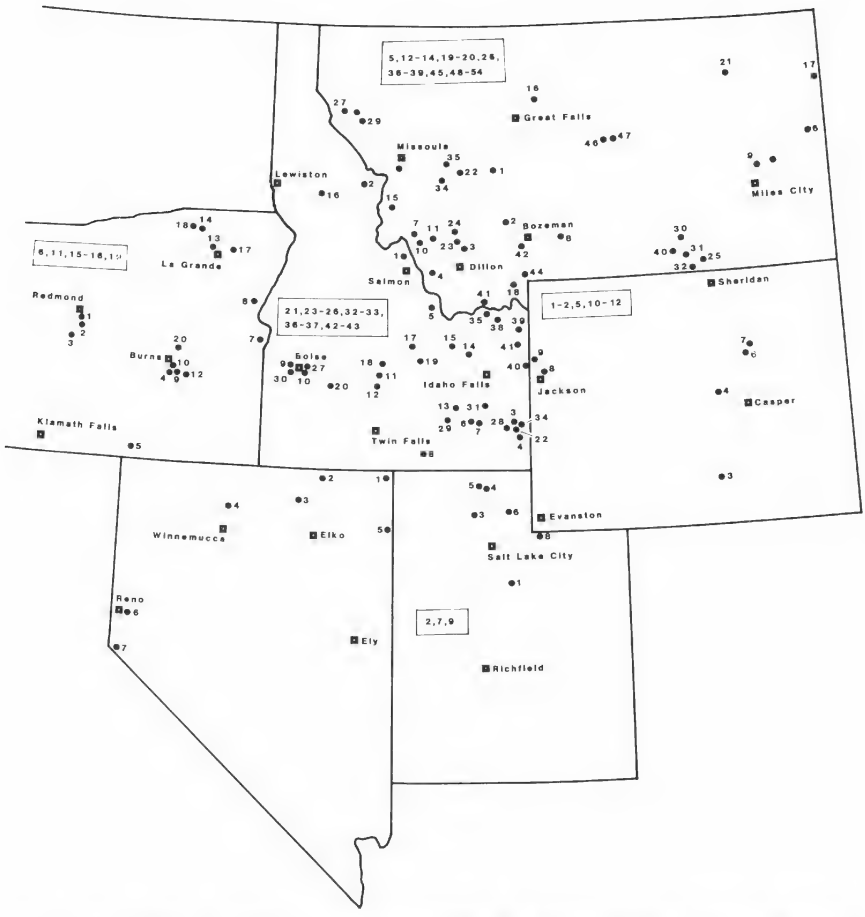


Figure 1. Fires listed in Table 1. Circles are fire locations. Boxed numbers represent observations not mappable or fires reported more than once. Squares are towns and cities.

times. The majority of these reports were made along principal travel routes (Figure 1). Documentation is lacking over large areas where travel was infrequent or not mentioned by the journalist.

Whether early travelers would mention fire seems to have depended on the observer, vegetative type, and season. For example, Lewis and Clark carefully noted events and landscape appearance for scientific purposes (Thwaites 1959). Ten different fires and burned landscapes were cited (Table 1). Others seemed to record only unusual events. Burned landscapes, apparently common in many areas, may not have been mentioned by various journalists. When burned landscapes were recorded, it often was in reference to destruction of grass needed for horse forage. This was experienced by Peter Skeen Ogden (Davies 1961), Maximilian Prince of Weid (Thwaites 1966c),

Lieutenant Mullan (1863), and DeLacy (Montana Historical Society 1902) during the period 1826-63. A fire in progress, however, was likely to be noted. In some regions, fire observations were unlikely because fire was an unimportant ecological force. For example, wildfires were apparently rare on the Laramie plains in 1832; Captain Bonneville noted that the short, scanty growth of grasses was insufficient for hunters to set on fire in the autumn (Todd 1961). There is a dearth of reports from sparsely vegetated regions in the drier, sagebrush valleys. Mention of fire is also unlikely in those journals covering travel during cool seasons or rainy periods when weather conditions precluded fire. Consequently, there is little or no mention of fire in these journals and reports.

Indian-set fires were apparently the primary ignition source over wide areas at lower and middle elevations. Of the 145 references to fires listed in Table 1, 60 (41 percent) were attributed to Indians; 7 (5 percent) were attributed to non-Indians, and 78 (54 percent) made no mention of ignition source. Very likely some lightning fires were inaccurately attributed to Indians, and the fires of unknown origin were caused by both Indians and lightning. Nevertheless, the available record does indicate that Indian-set fires were common (Gruell in press).

The amount of fire on early landscapes seems to have varied by region, depending on weather and fuels. Extensive fires swept through grasslands every year during the period 1832-1877 at various locations in central and eastern Montana as suggested by Denig (Ewers 1961), Catlin (1891), and Havard (1878). Other reports show that very large fires occurred in the forested regions of northwestern Montana during exceptionally dry years. One of these burned about 853 square kilometers (530 square miles) in 1889 on the Lewis and Clark Forest Reserve (presently Lewis and Clark, Flathead, and Lolo National Forests) (Ayres 1901). Likewise extensive fires were reported by Beaver Dick Leigh in 1875 and 1878 in southeastern Idaho (Thompson and Thompson 1982), in 1879 by Thomas Moran in Wyoming (Fryxell 1943), and Captain Bonneville (Todd 1961) and Nathaniel Wyeth (Young 1899) in 1834 in western Idaho and eastern Oregon.

During early government surveys, some observers recorded the effects of fires on vegetation. After an extensive survey of Utah's forests in the 1870's John Wesley Powell (Stegner 1962) concluded that fires set mainly by Indians prevented establishment of trees.

Ayres (1901) reported extensive, almost continuous, burns on the foothills along the east slope of the Rocky Mountain Front. Only weeds and brush, including willow and aspen, were observed on recent burns.

In the Little Belt Mountains of north-central Montana, Leiberg (1904a) noted that during the Indian occupancy there were many fires. Leiberg concluded that these fires were responsible for perpetuating grassy parks on slopes and in the larger canyons.

It was widely recognized that burning of grass improved forage. In August 1833, in the Wood River Valley below Ketchum, Idaho, Peter Townsend observed that the prairie had been recently burned by Indians to improve the crops of next year (Thwaites 1966a).

In October 1943 southeast of Boise, Idaho, Fremont (1887) noted green grass wherever Indian-set fires had burned the landscape.

Similarly, in September 1853, near the confluence of the Little Blackfoot and Clark

Fork Rivers in Montana, Lt. John Mullan (1855b) found young green grass growing abundantly in many places that had been burned over.

In September 1859, while traveling between the Bighorn River and present day Sheridan, Wyo., Capt. W. F. Raynolds (1868) encountered an extensively burned landscape and the temporary absence of grasses. Raynolds believed this was caused by Indian fires. He noted that although the country was black and forbidding, in the spring it would be most beautiful.

Fire's effect on woody plants was also noted by early explorers. For example, Havard (1878) described slow crown sprouting by woody vegetation, after prairie fires in central and eastern Montana. Fremont (1887) observed in August 1843 that Indian fires prevented the establishment of trees on the lower Bear River near present day Tremonton, Utah. The custom of burning to produce better grass had suppressed willow growth.

In July 1850, Byron McKinstry recorded that much aspen had been killed by fire the previous year in the Portneuf Mountains west of Soda Springs (McKinstry 1975).

Fire's effect on valley bottom vegetation in southwestern Montana was noted in the Lewis and Clark journals. Lewis recorded on 4 August 1805, near the outlet of the Big Hole River that in some localities the Indians appeared to have destroyed a great proportion of the low density timber by setting fire to the bottoms (Thwaites 1959).

A subsequent journal entry suggests that these fires were common. On the upper Beaverhead River, Lewis commented that fires were "frequently kindled in these plains by the natives."

#### Conclusions

These historical fire observations demonstrated that fire was a major perturbation in the interior West. Many of these fires were set by Indians.

Based on the analysis of fire-scarred trees, fire history studies have documented the frequency of early fires in the major cover types of the northern Rocky Mountains, middle Rocky Mountains, and Owyhee Plateau. These studies suggest that fire periodicity varied with climate and fuels. Average pre-settlement fire intervals often ranged from 4 to 20 years in ponderosa pine/Douglas-fir (*Pinus ponderosa/ Pseudotsuga menziesii*) forests in the Bitterroot Valley of western Montana (Arno and Peterson 1983). Scar data from higher and cooler Douglas-fir/sagebrush (*Artemisia vaseyana*) ecotones in Yellowstone Park and southwest Montana suggest fire intervals of 20-40 years (Houston 1973, Arno and Gruell 1983). Shorter intervals probably prevailed in the drier grassland associations. Fire scar evidence in aspen stands in Ephraim Canyon, Utah, showed a mean fire interval of 7-10 years during the period 1770-1875 (Baker 1925). Burkhart and Tisdale (1976) report pre-settlement fire intervals in southwestern Idaho sagebrush-grass/western juniper (*Juniperus occidentalis*) ecotones were comparable to the 13-18 year interval found by Keen (1937) for ponderosa pine forests in eastern Oregon.

Frequent fires in dry regions inhibited optimal growth of woody vegetation. Today, the number and sizes of fires in these regions have been markedly reduced, and large areas have not burned since the late 1800's. This change has apparently been caused by the reduction of fine fuels by livestock, elimination of Indian ignitions, and efficient fire suppression (Gruell 1982). Where fires were frequent, the reduction of fire

has resulted in a dramatic increase in woody vegetation. In the Oregon Cascades and western Montana, for example, ponderosa pine is being successionally replaced by shade tolerant species (West 1969, Gruell and others 1982). On the Owyhee Plateau juniper has invaded the sagebrush and perennial bunchgrass type (Burkhart and Tisdale 1976). In the cool-dry regions of Yellowstone Park and southwestern Montana, Douglas-fir forests are now more densely stocked, and sagebrush/grasslands are being heavily invaded by trees (Houston 1973, Arno and Gruell 1983).

In general, fires have been less frequent in the moist regions of north Idaho and high-cold regions elsewhere (Loope and Gruell 1973, Arno and Davis 1980, Romme 1979, Barrett 1982). Fires were particularly prevalent during dry years 1910-1934. Since the early 1940's, the marked reduction in acres burned yearly has resulted in successional advances and reduced diversity (Gruell 1983).

Historical narratives documenting early fire occurrence provide an understanding of the past role of fire in shaping patterns of vegetation. These narratives and fire history studies demonstrate that fires have had a major influence on vegetation in the interior West. This knowledge can help land managers understand why vegetation has changed and aid in assessing the desired role of fire in the future.

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# Host Associations of Siphonaptera from Central Oregon

**Abstract**

Fifteen flea species (954 individuals) were recovered from three sciurid, two cricetid, and one heteromyid species (541 captures, 370 individuals) during 2271 trap nights. Flea-host associations are described. The infestation rate and mean number of fleas per infested host was greater in male than in female *Eutamias amoenus* and *Peromyscus maniculatis*. Reproductively active males of these two species were infested more often than their reproductively inactive conspecifics. Initial captures of *E. amoenus* were signififantly more often infested than recaptured individuals. The proportion of the *P. maniculatus* flea population comprised of *Monopsyllus wagneri*, and the mean number of fleas per infested host, was greatest in reproductively active and recaptured deer mice but lowes for *Opisodasys keeni* taken from hosts in these categories.

Few published accounts describe the flea fauna of Oregon. Subsequent to Hubbard's (1947) collections and compilation of findings, there have been limited reports on fleas of sciurids and cricetids (Hansen 1964, Lewis and Maser 1981, Gresbrink and Hopkins 1982, Haas 1982, Easton 1983). The present study was part of a statewide surveillance program in 1978 and 1980 to assess the risk from vector-borne pathogens. Flea-host associations, including flea sex ratios, reinfestation rates, and infestation by host sex and reproductive status, are presented herein.

## Materials and Methods

The study area is about 15 km SE of Bend, Deschutes County, Oregon, in T13S, R12E, S33; T18S, R12E, S33; and T19S, R13E, S13, 14, 15, 16, 22, 27. Ponderosa pine (*Pinus ponderosa*), western juniper (*Juniperus occidentalis*), big sagebrush (*Artemesia tridentata*), rabbitbrush (*Chrysothamnus nauseosus*), and bitterbrush (*Purshia tridentata*) are common in the study area. Other xeric species present are green manzanita (*Arctostaphylos patula*), buckwheat (*Eriogonum* sp.), indian paintbrush (*Castilleja* sp.), and dwarf monkeyflower (*Mimulus nana*). Hillocks and exposed outcrops of basalt are not uncommon. Elevations range from about 1250 to 1370 m above sea level. Monthly average temperatures and rainfall during June, July, and September range from 12.8° C to 17.1° C and 0.91 to 2.8 cm respectively. The annual means are 7.6° C and 30.8 cm.

Small mammals were collected with Sherman live-traps (7.6 x 8.9 x 22.9 cm) during June, July, and September 1979 and June and July 1980. Two traps baited with oatmeal were placed at each station; distance between stations was about five meters. Each line usually consisted of 20-24 traps and was checked for three to four nights. Each mammal captured was anesthetized with diethyl ether, then thoroughly brushed for fleas in a white enamel pan. Host species, sex, capture-recapture status, and numbers of fleas and ticks were recorded. Specimens recovered from each host were placed in a labeled vial containing 2 percent saline solution. Fleas were subsequently

identified and their sex determined by personnel at the Center for Disease Control, Vector-Borne Disease Division, Plague Branch, Fort Collins, Colorado. Each mammal was toe- or ear-clipped and released at its site of capture after examination.

Tests for statistical significance were made, where appropriate, using z-values, chi-square, and Fisher's exact test.

## Results and Discussion

Fifteen flea species (954 individuals) were recovered from six host species (541 captures, 370 rodents) during 2271 trap nights. Subsequent discussion include recaptured individuals except where noted.

### Fleas

Three flea families (Ceratophyllidae, Leptopsyllidae, and Hystrichopsyllidae) were represented by the following species: *Orchopeas sexdentatus* Baker, *Orchopeas leucopus* Baker, *Opisodasys keeni* Baker, *Oropsylla idahoensis* Baker, *Malaraeus telchinum* Rothschild, *Malaraeus euphorbi* Rothschild, *Monopsyllus wagneri* Baker, *Monopsyllus ciliatus* Baker, *Monopsyllus eumolpi* Rothschild, *Callistopsyllus terinus* Rothschild, *Catallagia decipiens* Rothschild, *Epitedia wenmanni* (Rothschild), *Meringis parkeri* Jordan, *Peromyscopsylla hesperomys* Baker, and *Rhadinopsylla sectilis* (Jordan and Rothschild).

### Hosts

Three rodent families (Sciuridae, Heteromyidae, and Cricetidae) were represented by the following species: yellow-pine chipmunk (*Eutamias amoenus*), 71 captures; Allen's chipmunk (*Eutamias senex=E. townsendii*) 2; golden-mantled ground squirrel (*Spermophilus lateralis*), 29; Great Basin pocket mouse (*Perognathus parvus*), 2; deer mouse (*Peromyscus maniculatus*) 431 and piñon mouse (*Peromyscus truei*), 6. Nearly all captured individuals were adults or subadults.

### Associations

*Orchopeas sexdentatus* (2 males, 1 female), commonly found on wood rats (*Neotoma* spp.), were collected only from *P. maniculatus* and *P. truei.* Although the study site was within the range of the dusky-footed wood rat (*N. fuscipes*) none were captured.

One female *Orchopeas leucopus* was taken from *P. maniculatus.* This flea is common in the eastern U.S. on deer mice but was considered a rarity in the western U.S. by Hubbard (1947); no specimens had been recorded from central Oregon or northern California. The flea was collected at T18S, R12E, S33 on 12 September 1978.

The second most common species (38.5 percent of all fleas) on *P. maniculatus* was *Opisodasys keeni.* By comparison, at Crater Lake National Park (Gresbrink and Hopkins 1982), *O. keeni* constituted only 2.1 percent of the *P. maniculatus* fleas. In the present study, 96.2 percent of *O. keeni* specimens were taken from deer mice. Small numbers were collected from all other host species in this study except *P. parvus.* Hubbard (1947) listed no records from *E. amoenus, S. lateralis,* or *P. truei.*

*Oropsylla idahoensis* (5 males, 7 females) was found on *S. lateralis* at twice the frequency of any other flea species. Accidental infestations were noted on *P. maniculatus* and *E. amoenus,* neither of which were recorded as *O. idahoensis* hosts by Hubbard (1947) but which were found infested in very small numbers at Crater Lake National

TABLE 1. Occurrence of flea species on mammals near Bend, Oregon, 1978 and 1980.

| | Eutamias amoenus (71)** | | | | Eutamias senex (2)** | | | | Spermophilus lateralis (29)** | | | | Perognathus parvus (2)** | | | | Peromyscus maniculatus (431)** | | | | Peromyscus truei (6)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percent Infested | No. of Fleas | Mean* | Maximum Number | Percent Infested | No. of Fleas | Mean* | Maximum Number | Percent Infested | No. of Fleas | Mean* | Maximum Number | Percent Infested | No. of Fleas | Mean* | Maximum Number | Percent Infested | No. of Fleas | Mean* | Maximum Number | Percent Infested | No. of Fleas | Mean* | Maximum Number |
| **Orchopeas sexdentatus** | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 0.5 | 2 | 1.0 | 1 | 16.7 | 1 | 1.0 | 1 |
| **Orchopeas leucopus** | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 0.2 | 1 | 1.0 | 1 | — | — | — | — |
| **Opisodasys keeni** | 8.5 | 8 | 1.3 | 2 | 50.0 | 1 | 1.0 | 1 | 3.4 | 1 | 1.0 | 1 | — | — | — | — | 39.2 | 307 | 1.8 | 15 | 16.7 | 2 | 2.0 | 2 |
| **Oropsylla idahoensis** | 1.4 | 1 | 1.0 | 1 | — | — | — | — | 24.1 | 9 | 1.3 | 2 | — | — | — | — | 0.2 | 2 | 2.0 | 2 | — | — | — | — |
| **Malaraeus telchinum** | 7.0 | 5 | 1.0 | 1 | — | — | — | — | — | — | — | — | — | — | — | — | 5.3 | 29 | 1.3 | 2 | — | — | — | — |
| **Malaraeus euphorbi** | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 0.2 | 1 | 1.0 | 1 | — | — | — | — |
| **Monopsyllus wagneri** | 16.9 | 12 | 1.0 | 1 | 50.0 | 2 | 2.0 | 2 | 10.3 | 3 | 1.0 | 1 | — | — | — | — | 43.9 | 354 | 1.9 | 6 | 16.7 | 1 | 1.0 | 1 |
| **Monopsyllus ciliatus** | 1.4 | 1 | 1.0 | 1 | — | — | — | — | 3.4 | 1 | 1.0 | 1 | — | — | — | — | — | — | — | — | — | — | — | — |
| **Monopsyllus eumolpi** | 49.3 | 94 | 2.7 | 10 | 50.0 | 1 | 1.0 | 1 | 3.4 | 1 | 1.0 | 1 | — | — | — | — | 2.7 | 13 | 1.1 | 2 | 33.3 | 2 | 1.0 | 1 |
| **Callistopsyllus terinus** | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 0.2 | 1 | 1.0 | 1 | — | — | — | — |
| **Catallagia decipiens** | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 5.1 | 24 | 1.1 | 3 | — | — | — | — |
| **Catallagia** sp. | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 1.9 | 10 | 1.3 | 2 | — | — | — | — |
| **Meringis parkeri** | — | — | — | — | — | — | — | — | 3.4 | 1 | 1.0 | 1 | 100 | 2 | 1.0 | 1 | 5.1 | 23 | 1.0 | 2 | — | — | — | — |
| **Meringis** sp. | — | — | — | — | — | — | — | — | — | — | — | — | 100 | 3 | 1.5 | 2 | 0.5 | 2 | 1.0 | 1 | — | — | — | — |
| **Epitedia wenmanni** | — | — | — | — | — | — | — | — | 6.9 | 2 | 1.0 | 1 | — | — | — | — | 1.6 | 7 | 1.0 | 1 | — | — | — | — |
| **Epitedia** sp. | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 0.5 | 2 | 1.0 | 1 | — | — | — | — |
| **Peromyscopsylla hesperomys** | — | — | — | — | — | — | — | — | 3.4 | 1 | 1.0 | 1 | — | — | — | — | 1.9 | 8 | 1.1 | 2 | — | — | — | — |
| **Peromyscopsylla** sp. | 1.4 | 1 | 1.0 | 1 | — | — | — | — | — | — | — | — | — | — | — | — | 2.6 | 11 | 1.0 | 1 | — | — | — | — |
| **Rhadinopsylla septilis** | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | 0.2 | 1 | 1.0 | 1 | — | — | — | — |
| TOTAL | 67.6 | 122 | 2.54 | 10 | 100.0 | 4 | 2.0 | 2 | 48.3 | 19 | 1.36 | 2 | 100.00 | 5 | 2.50 | 3 | 74.0 | 798 | 2.50 | 16 | 83.3 | 6 | 1.2 | 2 |

*Mean number of fleas per infested host.
**Number of animals captured in parenthesis.

Park (Gresbrink and Hopkins 1982) where *S. lateralis* harbored 97.6 percent of the *O. idahoensis* recovered.

*Malaraeus telchinum* is typically recovered from deer mice and other cricetids. This species was found on *P. maniculatus* and *E. amoenus*, the latter a host not listed by Hubbard (1947).

*Malaraeus euphorbi* was first described in 1905 from an individual removed from a deer mouse in British Columbia; Hubbard (1947) listed no other specimens. Subsequently, Hansen (1964) reported taking one individual from *P. maniculatus* on Steens Mountain in southeastern Oregon. One male *M. euphorbi* was collected from the same host species at T18S, R12E, S33 on 10 June 1980.

The preeminent flea species in this study was *Monopsyllus wagneri,* accounting for 39.0 percent of the total fleas collected. It was the principal flea of *P. maniculatus*; more individuals ( = 1.9) were recovered per infested deer mouse than any other species on this host. *M. wagneri* was also taken in small numbers (4.8 percent of the total) from all other rodent species except *P. parvus*. Hubbard (1947) did not list this species from *E. senex*.

Only two *Monopsyllus ciliatus* (1 male, 1 female) were recovered, one from its preferred host, *E. amoenus,* the other from *S. lateralis*. The latter was not recorded by Hubbard as a host, but did harbor the species at Crater Lake National Park (Gresbrink and Hopkins 1982).

*Monopsyllus eumolpi* was the third most common species collected; 84.7 percent of the individuals were taken from *E. amoenus*. All other rodents except *P. parvus* yielded this flea in small numbers.

One female of the rare *Callistopsyllus terinus* was collected on 10 June 1980 at the same trap line as *Malaraeus euphorbi*. The host was a male *P. maniculatus*.

Twenty-four *Catallagia decipiens* (all females) were collected solely from *P. maniculatus*. This was the fourth most common flea on deer mice.

*Epitedia wenmanni* (8 males, 1 female) were taken from *P. maniculatus* and *S.*

TABLE 2. Summary of fleas collected near Bend, Oregon, 1978 and 1980.

| Species | Number | Percent of Total | Percent of Hosts Infested | Mean No./ Infested Host | Sex* Ratio |
|---|---|---|---|---|---|
| **Orchopeas sexdentatus** | 3 | 0.3 | 0.6 | 1.0 | — |
| **Orchopeas leucopus** | 1 | 0.1 | 0.2 | 1.0 | — |
| **Opisodasys keeni** | 319 | 33.4 | 32.9 | 1.8 | 37:63 |
| **Oropsylla idahoensis** | 12 | 1.3 | 1.7 | 1.3 | — |
| **Malaraeus telchinum** | 34 | 3.6 | 5.2 | 1.2 | 26:74 |
| **Malaraeus euphorbi** | 1 | 0.1 | 0.2 | 1.0 | — |
| **Monopsyllus wagneri** | 372 | **39.0** | 38.1 | 1.8 | 34:66 |
| **Monopsyllus ciliatus** | 2 | 0.2 | 0.4 | 1.0 | — |
| **Monopsyllus eumolpi** | 111 | 11.6 | 9.4 | 2.2 | 38:62 |
| **Callistopsyllus terinus** | 1 | 0.1 | 0.2 | 1.0 | — |
| **Catallagia decipiens** | 24 | 2.5 | 4.1 | 1.1 | — |
| **Catalagia** sp. | 10 | 1.0 | 1.5 | 1.3 | — |
| **Meringis parkeri** | 26 | 2.7 | 4.6 | **1.0** | 69:31 |
| **Meringis** sp. | 5 | 0.5 | 0.8 | 1.3 | — |
| **Epitedia wenmanni** | 9 | 0.9 | 1.7 | 1.0 | — |
| **Epitedia** sp. | 2 | 0.2 | 0.4 | 1.0 | — |
| **Peromyscopsylla hesperomys** | 9 | 0.9 | 1.7 | 1.0 | — |
| **Peromyscopsylla** sp. | 12 | 1.3 | 2.2 | 1.0 | — |
| **Rhadinopsylla sectilis** | 1 | 0.1 | 0.2 | 1.0 | — |

*Computed only where more than 25 fleas were collected.

*lateralis*. Hubbard (1947) did not report this species from the latter host. *E. wenmanni* was believed by Hubbard to be a cool weather flea, rarely taken in the Great Basin after March. Specimens were recovered during mid-June and September.

Kangaroo rats (*Dipodomys* spp.) are the true hosts of *Meringis parkeri* (Hubbard 1947). The flea was not uncommon on *P. maniculatus* and was also recovered from *P. parvus* and *S. lateralis*. The latter was not listed as a host by Hubbard (1947).

*Peromyscopsylla hesperomys* was collected in small numbers (2 males, 7 females) from *P. maniculatus* and *S. lateralis*. Hubbard (1947) did not report finding this species on *S. lateralis*.

A deer mouse harbored one male *Rhadinopsylla sectilis*, a rather rare species, at T19S, R13E, S15. Hubbard (1947) indicated that the species is a winter flea; the above individual was collected on 9 June 1980.

### Effect of Host Sex, Reproductive Status, and Recapture Upon Infestation

Differential infestation rates occurred by host sex among the three common mammalian species, *Eutamias amoenus*, *Spermophilus lateralis*, and *Peromyscus maniculatus*. The infestation rate was greater in males than females except for *S. lateralis*. *Similar* observations on rodents have been made by Tipton and Mendez (1968), Amin (1976), and Gresbrink and Hopkins (1982).

Thirty-six female *E. amoenus* were collected with 63.9 percent infested, compared to 71.4 percent of 35 males. The mean number of fleas per infested host was also greater for males, 2.72 versus 2.35 for females. *S. lateralis* showed the greatest differences by sex; 16.7 percent of 12 males had fleas compared to 64.7 percent of 17 females. An average of 1.33 fleas was recorded per infested female compared to 1.50 fleas per male. However, the number of hosts is small. A statistically significant difference ($P < 0.01$) was demonstrated by host sex for *P. maniculatus*; the frequency of infestation was 78.8 percent for 283 males but only 64.9 percent of 148 females. Concommitantly, 2.59 fleas were collected from the average infested male and 2.29 from infested females.

The significantly increased incidence of infestation among male *P. maniculatus* is the result of the presence of reproductively active individuals. Deer mice with descended testes were infested in 86.1 percent of 173 captures compared to 68.2 percent of the 110 mice in which the testes were abdominal; the difference is significant ($P < 0.001$). Whether this is a consequence of host physiology or behavior is unknown. A mean of 2.64 fleas was recorded for active males and 2.44 for inactive individuals. Infestation rates and mean numbers of fleas were nearly identical for reproductively active (91) and inactive (57) females, 64.8 percent and 2.39 versus 63.2 percent and 2.29, respectively.

*Eutamias amoenus* with descended testes (19) also possessed higher infestation rates and mean numbers of fleas than individuals with abdominal testes (17), 78.9 percent and 3.07 for the former compared to 64.7 percent and 2.09 for the latter. Among inactive females, 61.1 percent were infested with a mean of 3.18 fleas compared to 64.7 percent and 1.64.

No significant correlation was found in the infestation rate or mean number of fleas when compared with capture-recapture data except that in *E. amoenus* 74.5 percent of the initial captures (55) had fleas compared to 48.8 percent of the 16 recaptures ($P < 0.05$). An average of 2.34 and 3.71 fleas were collected respectively. The

percent of *P. maniculatus* infested was nearly identical for initial captures (73.6 percent, 280 individuals) and recaptures (74.8 percent, 151 individuals). A decline in the mean number of fleas per infested mouse was recorded, 2.61 compared to 2.30.

### Peromyscus Maniculatus Flea Populations

Significant differences occurred in the proportion of the two predominant *P. maniculatus* fleas, *Opisodasys keeni* and *Monopsyllus wagneri,* depending upon the hosts' reproductive and capture status. An equal percentage (43.2 percent) of both species was found among sexually inactive male hosts, with other species accounting for the remaining 13.4 percent of 183 fleas. However, of 394 fleas collected from males whose testes had descended, 45.7 percent were *M. wagneri* and 33.0 percent were *O. keeni.* Testing for significance with a 2 x 3 contingency table yielded a $P<0.05$. Among reproductively inactive male deer mice, a mean of 2.14 *O. keeni* and 1.84 *M. wagneri* were collected per infested host. Parralleling the percent infested, the mean for *O. keeni* declined to 1.69 while *M. wagneri* increased to 2.02 on sexually active male mice.

Similarly, the percentage of the flea population comprised of *O. keeni* was higher in sexually inactive females (53.5 percent) than on active females (38.5 percent) while *M. wagneri* amounted to 32.6 percent of the flea complement on inactive females (86 fleas), but 49.6 percent of the fleas on active female hosts (135 fleas). Other fleas accounted for 13.9 percent and 11.9 percent respectively. The differences are significant ($P<0.05$). The mean number of *M. wagneri* per infested host was nearly identical for reproductively inactive (1.65) and active (1.68) females, while 2.19 *O. keeni* were recorded on inactive females compared to 1.53 on active individuals.

A significant association ($P<0.001$) occurred among the flea species on initially captured individuals compared to those recaptured one to three nights later. Both *O. keeni* and *M. wagneri* comprised 42.9 percent of the flea population (538) on initial captures. On recaptures, however, only 29.2 percent of the 260 fleas were *O. keeni* while *M. wagneri* accounted for 47.3 pecrent. Other species totaled 14.2 percent and 23.5 percent on initial captures and recaptures respectively. The mean number of *M. wagneri* was 1.80 on first captures and 2.02 on recaptures while the numbers of *O. keeni* declined from 2.04 on first captures to 1.36 on recaptures. The difference is significant ($P<0.001$).

In summary, the proportion of the flea population consisting of *M. wagneri* and the mean number of fleas per infested host was greatest in reproductively active and recaptured deer mice but lowest for *O. keeni* taken from hosts in these categories.


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# Indicator Species for Assessing Overuse of Campsites

**Abstract**

Trampling caused changes in the species composition of subalpine vegetation in the Bighorn Crags, Lemhi County, of central Idaho. While overall plant cover predictably decreased, certain species increased in both percent cover and percent frequency on lightly used campsites. Two of these, *Erigeron peregrius* (Pursh.) Greene and *Antennaria lanata* (Hook.) Greene may be useful as indicators of increasing use.

## Introduction

Indicator species have long been used for a variety of purposes: to locate metal deposits or other soil constituents, to determine habitat type, and to determine range condition and trend (Stoddart *et al.* 1975, Daubenmire 1959). In this paper I propose an additional use of indicator species. My work in the Idaho Primitive Area suggests that certain plant species may serve as early indicators of overuse on campsites.

Trampling of camping areas reduces plant cover, ultimately creating an area of bare compacted soil which then erodes rapidly. [See Sills and Carrow (1983) for discussion and references on the relation of vegetal cover, litter, and bare ground to erosion; see also Liddle (1975) for a review of the literature on the numerous effects of trampling.] Particularly in subalpine and alpine areas, a site at this stage will take decades to recover (Strand 1972, Willard and Marr 1971). This is a particular problem in many parts of the national wilderness system where managers are attempting to minimize the visible impact of man. A plant species that has higher cover with moderate amounts of use could indicate deterioration of site condition before erosion became so serious that restoration was nearly impossible. Working in a dune ecosystem in Massachusetts, McDonnell (1981) found such a species, the beach grass *Ammophila breviligulata* Fernald. Long-term moderate trampling had no effect on total cover of the community, but the cover of *A. breviligulata* increased whereas the other dominant species in the community, *Hudsonia tomentosa* Nutt., was almost eliminated. McDonnell's data support the use of pure stands of *A. breviligulata* to indicate moderate use levels.

Before the value of species as indicators can be evaluated, changes in species composition must be documented. Although many workers in many parts of the world have observed loss of ground cover with increased trampling, relatively few have considered the effect of trampling on individual species. In general, sedges and grasses resist trampling better than forbs (Cole 1978, Landals and Scotter 1973, Burden and Randerson 1972, Palmer 1972, Laing 1961). Species composition shifts to native invaders, exotics, drought-resistant species, and those that can tolerate puddling and trampling (Crawford and Liddle 1977, Liddle and Greig-Smith 1975, Helgath 1975, Westhoff 1967, Bates 1935). To document this change in species composition for one area, I under-

took a study of trampling effects on vegetation in the Bighorn Crags of the Idaho Primitive Area.

### Methods

The Bighorn Crags, Lemhi County, is a subalpine region on the eastern-most edge of the Idaho Primitive Area, approximately 70 miles due west of Salmon. The study was conducted on four lakes at the northern end of the Crags—Shoban, Birdbill, Gentian, and Big Clear; all four are at about the same elevation (2880 meters) and have comparable soils. The dominant conifer is *Abies lasiocarpa* (Hook.) Nutt.[1], with *Luzula hitchcockii* Hamet-Ahti and *Vaccinium scoparium* Leiberg making up much of the understory. In a study in the Eagle Cap Wilderness in the Wallowa Mountains of Oregon, Cole (1978) found that, of all the types he studied, this habitat type was one of the most sensitive to trampling damage.

In July and August, 1975, I sampled 19 campsites, 6 lightly used, 11 heavily used, and 2 apparently unused. Several of these sites were resampled in 1976. This resampling showed that the results obtained in 1975, and reported here, are highly repeatable. Relative use was determined by personal observation and by conversations with frequent users of the area. I assumed that the center of the campsite was the fire ring, and that use decreased as distance from the fire ring increased. On control sites, the center was arbitrarily designated. From the site center, I marked concentric circles that had radii of 2.4, 4.9, and 7.3 m. The outermost circle was large enough to include most of the visibly affected area on most of the sites. Every 40 cm around each of the circles, percent cover was estimated for each species in 20 x 50 cm quadrats. Sampling methods are described in detail in Daubenmire (1968). Percent frequency was also calculated. On opposite edges of each quadrat I also took two point samples to assess percent cover of litter, vegetation, soil, rock, and erosion pavement. (Erosion pavement is the hard gravelly surface produced after the fine soil particles have been eroded. This surface appears to be more resistant to further erosion.) Of the 19 campsites sampled, I eliminated 5 that were much wetter and had a substantially different species composition. Similarity indices, in which the index of similarity was the number of species in common between two sites divided by the total number of species on both sites taken together, confirmed that these 5 were indeed atypical. This left 5 heavily-used, 5 lightly-used, and 2 control sites for comparison. Because they had similar physical parameters, similar tree species, and high indices of similarity of understory vegetation, these sites probably all originally maintained similar plant communities. Data on percent cover and frequency were normalized using an arcsine transformation; the transformed data were averaged for each species. Each species thus had a frequency and cover value for each site, use-level, and distance. The sites at the same use-level were then taken as replicates. The experimental design was an unbalanced three-way factorial, analyzed by a three-way ANOVA. The main effects were species, use-level, and distance; all possible interactions were tested. The design was unbalanced because there were only two sites with no use, giving only two values in the cells with the lowest use-levels. Individual means were compared with Tukey's W statistic (see Ott 1977).

Once significant trends had been established, possible indicators were chosen (see

[1]Species determinations according to Hitchcock and Cronquist (1973).

discussion for criteria) and their value as indicators checked by making sure they responded similarly on all sites.

## Results

### Ground Cover

Table 1 shows gross changes in ground cover, as determined by point samples. Not surprisingly, the percentage of ground covered by vegetation decreased as trampling increased. Differences between use levels at each radius are highly singificant.

TABLE 1. Mean species number and mean percentages of ground covered by litter, vegetation, rock, soil, and erosion pavement on heavy-use, light-use, and control sites.

| | Heavy-Use Sites | | | Light-Use Sites | | | Control Sites | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2.4 m | 4.9 m | 7.3 m | 2.4 m | 4.9 m | 7.3 m | 2.4 m | 4.9 m | 7.3 m |
| Litter | 42 | 44 | 42 | 44 | 42 | 43 | 39 | 38 | 40 |
| Vegetation | 4 | 10 | 10 | 27 | 30 | 32 | 52 | 56 | 24 |
| Rock | 10 | 15 | 14 | 3 | 9 | 11 | 2 | 6 | 7 |
| Bare soil | 11 | 8 | 8 | 15 | 13 | 9 | 3 | <1 | 2 |
| Erosion pavement | 20 | 19 | 12 | 2 | <1 | <1 | | | |
| Number of species | 7 | 11 | 12 | 13 | 16 | 17 | 8 | 10 | 11 |

The percentage of rock may be independent of amount of use. If trampling proceeds to the point of causing erosion, however, some additional rock may be exposed. Hence, there is significant increase in surface rock on the heavy-use sites as compared to controls.

Bare soil was significantly greater on used sites than on control sites. There was a slight decrease in bare soil as use changed from light to heavy, although this change is not significant. Although this may appear anomalous at first, it can be explained by increased erosion on the heavy-use sites, which produces an erosion pavement, and decreases the proportion of bare soil.

Litter remained virtually constant over all use levels. If erosion were occurring on the heavy-use sites, litter should decrease; however, the annual deposition of fir and pine needles may be sufficient to maintain a litter layer even on sites where erosion is occurring.

With the exception of percent cover of litter, then, changes in ground cover concur with the results of previous research. Plant cover decreases with use, while bare ground (the sum of rock, soil, and erosion pavement values) increases.

### Species Number

The mean number of species on the light-use sites is significantly greater than on either the heavy-use sites or the control sites. There is no significant difference, however, between the control and heavy-use sites. This agrees with the results of Landals and Scotter (1973) who found an increase in species number with light trampling, followed by a decrease as trampling pressure mounted. It appears that some colonizing species take advantage of the increased bare ground, reduced competition, and possibly an altered nutrient regime (Streeter 1971) occurring on lightly used sites, thus increasing the number of species. As trampling increases, though, fewer species can survive, so the total number again declines. My data on individual species further support this hypothesis.

### Frequency and Cover of Individual Species

The analyses of variance for percent frequency and percent cover produced similar results (Table 2 and 3). Not surprisingly, the main effects were each strongly significant. There was a significant ($p<0.001$) interaction between species and use-level, showing that different species are strongly affected by differences in use. All other interactions (species-with-distance, use-with-distance, and species-with-use and -distance) were not significant.

Except for the conifer seedlings, each species may be placed in one of two categories: those that decrease with heavy use and those that increase at moderate use-levels. The conifer seedlings were newly germinated and their appearance in their first year was independent of trampling pressure. Although there were many seedlings in 1975, few

TABLE 2. Mean percent frequency of species on heavy-use, light use, and control campsites. Differences between levels of use are significant ($p < 0.001$). Differences between distances within the same level of use are not significant.

| | Heavy-Use Sites | | | Light-Use Sites | | | Control Sites | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | 2.4 m | 4.9 m | 7.3 m | 2.4 m | 4.9 m | 7.3 m | 2.4 m | 4.9 m | 7.3 m |
| **Luzula hitchcockii** | 4 | 5 | 8 | 44 | 50 | 52 | 96 | 66 | 57 |
| **Vaccinium scoparium** | 22 | 42 | 37 | 38 | 50 | 64 | 88 | 92 | 90 |
| **Arnica latifolia** | | | | <1 | 5 | 5 | 24 | 8 | 17 |
| Mosses | | <1 | <1 | 30 | 26 | 27 | 27 | 6 | 19 |
| **Carex rossii** | 18 | 18 | 15 | 46 | 35 | 31 | 39 | 25 | 29 |
| **Phyllodoce empetriformis** | 2 | 3 | 4 | 4 | 8 | 14 | 10 | 1 | |
| **Chionophila tweedyi** | 18 | 19 | 20 | 20 | 31 | 32 | 5 | 5 | 17 |
| Grass | <1 | 3 | 3 | 3 | 5 | 6 | 4 | | 4 |
| **Juncus parryi** | <1 | 3 | 2 | 38 | 31 | 16 | | 3 | 6 |
| **Pedicularis contorta** | 2 | 12 | 8 | 45 | 32 | 27 | | 3 | 13 |
| **Erigeron peregrinus** | | <1 | <1 | 20 | 14 | 10 | | | |
| **Hieracium gracile** | <1 | 1 | 1 | 38 | 28 | 24 | 3 | 3 | 7 |
| **Lewisia pygmaea** | <1 | <1 | <1 | 4 | 2 | 2 | | | |
| **Castilleja rhexifolia** | | | | 3 | 2 | 3 | | | |
| **Antennaria lanata** | <1 | | | 24 | 19 | 14 | | | |

TABLE 3. Mean percent cover of species on heavy-use, light-use, and control campsites. Differences between levels of use are significant ($p < 0.001$). Differences between distances within the same level of use are not significant.

| | Heavy-Use Sites | | | Light-Use Sites | | | Control Sites | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | 2.4 m | 4.9 m | 7.3 m | 2.4 m | 4.9 m | 7.3 m | 2.4 m | 4.9 m | 7.3 m |
| **Luzula hitchcockii** | <1 | 1 | 2 | 6 | 9 | 10 | 14 | 7 | 9 |
| **Vaccinium scoparium** | 1 | 5 | 6 | 5 | 9 | 13 | 18 | 26 | 26 |
| **Arnica latifolia** | | | | <1 | <1 | <1 | 4 | <1 | 1 |
| Mosses | | <1 | <1 | 3 | 2 | 2 | <1 | <1 | <1 |
| **Carex rossii** | <1 | 1 | <1 | 3 | 3 | 2 | 5 | 4 | 4 |
| **Phyllodoce empetriformis** | <1 | <1 | <1 | <1 | 2 | 4 | 3 | <1 | |
| **Chionophila tweedyi** | 1 | <1 | 1 | <1 | 2 | 2 | <1 | <1 | <1 |
| Grass | <1 | <1 | <1 | <1 | <1 | <1 | | <1 | |
| **Juncus parryi** | <1 | <1 | <1 | 4 | 4 | 2 | | <1 | 1 |
| **Pedicularis contorta** | <1 | <1 | <1 | 5 | 2 | 3 | | <1 | 2 |
| **Erigeron peregrinus** | | <1 | <1 | 2 | 1 | 1 | | | |
| **Hieracium gracile** | <1 | <1 | <1 | 2 | 1 | <1 | <1 | <1 | <1 |
| **Lewisia pygmaea** | <1 | <1 | <1 | <1 | <1 | <1 | | | |
| **Castilleja rhexifolia** | | | | <1 | <1 | <1 | | | |
| **Antennaria lanata** | <1 | | | 2 | 2 | 1 | | | |

survived to the following year and few new ones were produced. Conifer seedlings, therefore, do not fit any of the patterns characteristic of other groups of plants.

The species that decreased include the climax dominants, *Luzula hitchcockii, Vaccinium scoparium,* and *Arnica latifolia* Bong. Mosses, grasses (including *Poa secunda* Presl, *P. leibergii* Scribn., and *Trisetum spicatum* (L.) Richter), and *Carex rossii* Boott decrease similarly, although they appear to resist light trampling. Cover values for *Carex rossii* decreased even with light trampling whereas frequency values remained high, suggesting that individual plants produce less aboveground biomass and coverage, yet remain well-distributed over the area.

The remaining plants increased. The differences among use levels are small and not significant for *Phyllodoce empetriformis* (Sw.) D. Don, *Lewisia pygmaea* (Gray) Robins., and *Castilleja rhexifolia* Rydb.; but *Antennaria lanata, Erigeron peregrinus, Chionophila tweedyi* (Canby & Rose) Hend., *Juncus parryi* Engelm., *Pedicularis contorta* Benth., and *Hieracium gracile* Hook. show much more dramatic change, increasing both percent cover and percent frequency with moderate use.

#### Discussion

The species that increased account for the increase in species number with low levels of trampling. These disturbance species either resist trampling or are particularly suited for colonizing bare soil. Although many areas have a "trampling flora" of plants that are resistant to, or increase with, trampling, the Bighorn Crags trampling flora is unusual because there are no widespread invasive weeds. In the many studies done in England, the species that increase with trampling are ruderal r-strategists, such as *Plantago lanceolata* L., *Bellis perennis* L., *Poa pratensis* L., *Taraxacum officinale* Weber, and *Taraxacum laevigatum* (Willd.) DC. (Gadgil and Solbrig 1972), well-known for their rapid colonization of disturbed sites (Crawford and Liddle 1977, Liddle and Greig-Smith 1975). Conversely, in the Bighorn Crags trampling flora, the increasing species do not seem to have evolved under a selection regime that particularly favors r-strategists. Their success in the face of trampling may be more fortuitous than the product of generations of selection.

Some morphological characteristics of the plants may make them trampling resistant. First, with the exception of *Castilleja rhexifolia* and *Phyllodoce empetriformis,* all have primarily basal leaves, usually in rosettes. Second, all have tap roots or rhizomes, which allow the plant to survive complete defoliation for at least one season. Third, all are perennials, and therefore do not depend on setting seed every season. Such explanations may be overly simplistic, however, as many of the decreasing species have the same characteristics. Clearly growth form may allow trampling resistance, but is by itself insufficient to guarantee it.

It is important to remember that a study of this sort integrates both the long- and short-term responses of plants to trampling. Many studies (Bowles and Maun 1982, Hylgaard and Liddle 1981, Crawford and Liddle 1977) considered the immediate effects of trampling on various types of vegetation, which led Bayfield (1979) to call for longer-term studies. He noted that damage may be delayed until the first winter after trampling and that recovery proceeded at different rates in different plants. That is, the ability to recover depends both on the species and on the life-form (Hyl-

gaard 1980). In studies such as mine, the differences in species distribution with use level reflect both the plant's ability to survive trampling and its ability to recover.

One or more of the increasing species should be useful as indicators. For a species to be a good indicator of use, it must be widespread enough that it could potentially occur on any site in the area, yet it should be present in only low quantities in undisturbed plant communities, and increase substantially with low levels of use. High frequency or cover of the species must be ascribable to impact. Applying these criteria leaves the following possibilities: *Chionophila tweedyi, Erigeron peregrinus, Antennaria lanata, Juncus parryi, Pedicularis contorta,* and *Hieracium gracile.*

In otherwise undisturbed areas of the *Abies lasiocarpa/Luzula hitchcockii* habitat type, high frequency or cover of any of these six species indicate that an area is receiving some low level of use. The manager, though, needs to minimize the number of measurements necessary to show change in species composition. Thus the best indicators are those that are rare in the climax community—*Erigeron peregrinus* and *Antennaria lanata.* High frequency or cover of either indicate a disturbed site, one that will deteriorate further if use is continued.

Any of the data on ground cover or number of species could also be used, but these parameters require intensive sampling for determination. Percent frequency, on the other hand, can often be determined accurately enough by simple inspection. A single species is thus a more efficient key to the condition of the site.

## Conclusions

Certain plant species indicate increasing use on campsites. In areas in which the visible impact of man is to be minimized, such as statutory wildernesses, these species can be used to determine when use should be restricted or sites closed in order to prevent site deterioration and erosion. In the Bighorn Crags area of central Idaho, the most sensitive such indicators are *Antennaria lanata* and *Erigeron peregrinus*; these are rare in undisturbed vegetation but increase dramatically with low levels of use. Further studies may show these species to be useful elsewhere in the *Abies lasiocarpa/Luzula hitchcockii* habitat type.

Because any plant community contains species that respond differently to disturbance, such indicators should be available for other habitat types and other parts of the country. These indicator plants can then be used to help control human impact on any site that is particularly sensitive to overuse.

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# Effect of Forest Roads on Habitat Use by Roosevelt Elk

## Abstract

Radio locations of 6 female Roosevelt elk (*Cervus elaphus roosevelti*) were monitored for one year in the central Coast Range of Oregon. Frequency distributions of elk from paved and spur roads were compared with distributions of 200 randomly located points about paved and spur roads. Elk were located at half the expected frequency within a 500 m wide band surrounding paved roads. Significantly fewer ($P<0.05$) elk observations also were noted for a narrower band (125 m) about spur roads open to vehicular traffic, but no differences existed for elk locations about spur roads closed to vehicles. Effect of roads on elk use of habitat may be mitigated by a system of road closures.

## Introduction

Forest roads are necessary for the protection, administration, and utilization of managed forests. In the Pacific Northwest, the intensively managed forest commonly has 2 or more km of roads per km$^2$ of land. These intensities of roading are a source of concern because of the potential for harassment of wildlife caused by human use of the roads. The biological effect of such harassment can be elevated metabolism, which depletes energy available for production or storage. This may lead to death, reduced vigor, or reduced reproduction (Ward 1977, MacArthur *et al.* 1982). Animals may also avoid or abandon harassment-prone areas with subsequent reduced range of the population (Geist 1978).

Other studies have documented the effects of forest roads on Rocky Mountain elk (*Cervus elaphus nelsoni*) populations (Pedersen *et al.* 1979, Lyon 1979, Rost and Bailey 1979). This paper reports the effect of forest roads on habitat use by Roosevelt elk (*Cervus elaphus roosevelti*).

## Study Area and Methods

A 12-month radio-telemetry study of 2 bands of Roosevelt elk was conducted in 1978-79 in the 14 km$^2$ Alder Creek Basin of the Bureau of Land Management Coos Bay District, Oregon Coast Range (Witmer 1981). The area is rugged with vegetation of the Western Hemlock Zone (Franklin and Dyrness 1973). Forest cover of the area is dominated by 190-year-old stands of mixed conifer species interspersed with clear-cuts, regenerating conifer stands and hardwood stands aged 0-30 years. The areas

occupied by the north and south bands contained 4.5 and 2.9 km of paved through roads and 10.3 and 7.6 km of dirt or gravel-surfaced spur roads, respectively. Although we did not monitor traffic volume, there was heavy log and gravel truck traffic on the paved roads on weekdays. Outdoor recreationists utilized basin roads primarily on weekends.

Data collected during 3,635 daylight remote triangulations from roads of 6 radio-collared cow elk included distance to the nearest paved road and to the nearest spur road. A receiver and hand-held, two element yagi antenna were used. Triangulation on randomly-placed radio-collars was practiced until collar locations were consistently mapped within 115 m of their actual location. Signal bearings that intersected at nearly right angles were used to minimize error polygons. Ninety-five percent of elk locations were within 1.6 km (1 mile) of the investigator. Because elk were easily frightened at night, we discontinued collecting night location data early in the study. Frequency distributions of the distance of elk locations from roads (observed values) were compared with frequency distributions of expected values derived from 200 points located at random in each of the north and south band areas. These distributions were compared with the chi-square analysis and, if significantly different, the Bonferroni z-test was used to determine in which distance interval(s) there were significantly fewer elk locations than expected (Neu *et al.* 1974). Average distances of elk to roads by season were compared by analysis of variance.

All roads in the study area were open to the public with the exception of the spur road system in the south band's area which was closed to public vehicular traffic by a locked gate except during the 10-day elk hunting season in November.

#### Results and Discussion

Spur roads pervaded the study area; none of the 200 randomly located points within either area was more than 375 m from a spur road. Less than half of the 200 randomly located points were within 375 m of paved roads and the greatest distance from a random point to a paved road was over 1125 m. Thus elk could hardly escape proximity to spur roads but could position themselves at somewhat greater distances from paved roads.

We pooled elk locations for the 12-month period for the north and south bands, respectively, and found the cumulative frequency distribution of observed elk locations from paved roads to be significantly different from the expected frequency distribution ($P<0.05$). Fewer elk locations occurred in the 0-125 and 126-250 m distance intervals than expected ($P<0.05$) for each band (Figure 1). Elk use was reduced to approximately 50 percent of the expected use on a 500 m wide band of habitat associated with a paved road.

Distribution of elk was less affected by spur roads (Figure 1). Significantly fewer ($P<0.05$) north band elk locations occurred in the 0-62 m interval from spur roads. The cumulative frequency distribution of south band elk distances from spur roads was not significantly different ($P>0.05$) from the expected distribution (Figure 1), perhaps because this spur road system was closed to most vehicular traffic.

Elk distributions were affected by roads more in some seasons than others. The average distances of elk locations of each band to the nearest paved road and to the nearest spur road varied significantly between seasons ($P<0.05$). The greatest degree

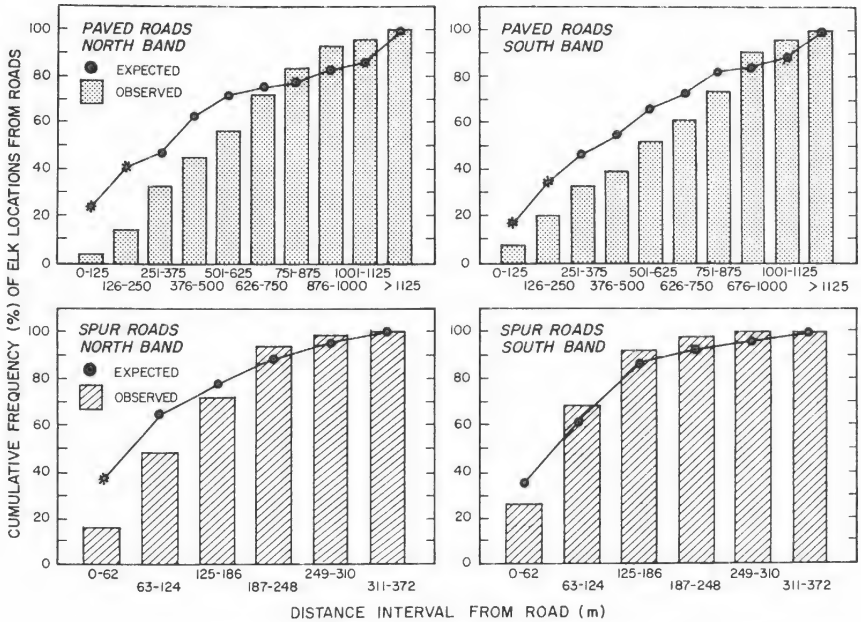


Figure 1. Cumulative frequency (%) disturbances for observed (bars) and expected (points) distances of elk from paved and spur roads. Values of expected distances that differ ($P < 0.05$) from observed distances are starred (*).

of observed avoidance of roads was exhibited by the 2 north band radio-collared cows during the season they bore their calves. However, 4 south band radio-collared cows, none of which were known to have calved that year, were farthest from roads during the rut. This suggests that if managers wish to reduce harassment of elk, their efforts might be most effective during calving (May-June) and rut (September-October). Elk avoided roads during the fall season which contained the hunting season, but not more than the yearly average. They did spend significantly more ($P<0.05$) time in cover during the hunting season (Witmer 1981).

The results of this study indicated that human activity on forest roads alters distributions of Roosevelt elk habitat use. The effect is comparable to that reported by Thomas (1979:122) for Rocky Mountain elk. This impact may be mitigated by road closures, especially during rut and calving seasons.

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# Biomass and Shoot Production in an Undisturbed Sagebrush-Bunchgrass Community

## Abstract

Total biomass in an undisturbed sagebrush-bunchgrass community was 1572 g dry weight per $m^2$ with 422 g aboveground and 1150 g belowground. Sagebrush contributed 127 g. Grass crowns, litter, and standing dead herbaceous plants contributed 233 g and the living shoots of herbs contributed 62 g per $m^2$. Twenty-five percent of the belowground biomass was in the upper decimeter of soil profile and 41 percent was in the surface two decimeters. Over a 4-yr period, herbaceous shoot production averaged 62 g per $m^2$ per yr with a range of 50-69 g. About 10 g per $m^2$ per yr was estimated to be produced by sagebrush.

Herbaceous shoot and shrub production in the sagebrush-bunchgrass community was at the low end of the scale of values cited in the literature for other kinds of semi-arid grassland communities in the western United States.

## Introduction

The vegetation of the semi-arid Columbia Basin region of interior Washington State under pre-settlement conditions consisted in a large part of vast stands of the *Artemisia tridentata/Agropyron spicatum* association (Daubenmire 1970). Following settlement by European people about 150 years ago much of the land formerly occupied by native plant communities has been under cultivation for dryland wheat and irrigated crops. A few remnant stands of native plant communities can be found, but these are mostly confined to steep slopes or other places with extremely rocky soil. Only a few of the remnant stands have not been subjected to years of grazing by domestic livestock. Some of the undisturbed remnant stands have been described in terms of plant species composition, canopy cover, climate, and soil properties (Daubenmire 1970). However, there is relatively little information concerning biomass and aboveground productivity in undisturbed communities. There is an increasing societal desire to obtain more crop and meat production from semi-arid lands, and it is important to document the status of native plant communities before they become further modified by man's land management practices (Coupland 1979).

This study determined above and belowground biomass and some of the dynamic aspects of production in a relatively undisturbed sagebrush-bunchgrass community using harvest-sample methods. This is the most complete data set of its kind for the sagebrush-bunchgrass region.

## Location and History of the Study Site

The study community is located on the United States Department of Energy's 1400 $km^2$ Hanford Site in Benton Co., Washington, T10N R26E S35 at an elevation 390 m above mean sea level. The community had been grazed by livestock prior to govern-

ment ownership in 1943, but since then the land has not had livestock grazing. The scarcity of *Bromus tectorum* (an aggressive, alien, annual grass) was regarded as evidence of the undisturbed status of the community (Daubenmire 1975). Wildfires were not known for the study site in the years before 1943; however, a part of the community was burned by a wildfire in August 1973 which caused a minor relocation of sampling plots in 1974.

#### Methods Employed

Two 300x300 m study plots were established in a homogeneous stand of vegetation representative of the *Artemisia tridentata/Agropyron spicatum* association. Inside the two study plots six smaller areas each 15x30 m (blocks) were randomly located and marked. Periodically throughout the spring growing season of 1971, 1972, 1973, and 1974 two 0.5 $m^2$ frames were randomly located within each block. Each circular frame was hand clipped of all aboveground plant material five times between March and June. Both 300x300 m plots were sampled in 1971, but in the years 1972, 1973, and 1974 only one of the study plots was sampled. In 1972, 1973, and 1974 eight blocks were sampled using 16 frames (as compared to 24 frames in 1971).

Live shoots were separated from dead shoots according to five botanical categories: shrubs, perennial grasses, annual grasses, perennial forbs, annual forbs, and half-shrubs. The harvested material was oven dried at 50°C and weighed. Results are expressed in grams dry weight per $m^2$. Grass crowns were cut off at ground level using a metal hack saw blade. The crown material was washed to remove attached soil particles, dried, and weighed. Results are expressed in grams dry weight per $m^2$. Litter was vacuumed from the ground, dried, and weighed. Aliquots of litter were burned in a muffle furnace to determine ash content. Litter weights are expressed in grams per $m^2$ with ash concentrations subtracted from the total dry weight.

Sagebrush shrubs were clipped and separated into leaves, standing live wood, standing dead wood, and wood litter. Results are expressed in grams dry weight per $m^2$.

Soil cores were taken at 1 dm depth intervals to a depth of 0.8 m from a location near the center of each circular frame. The soil cores were washed over a fine mesh screen to separate soil particles from roots, and the roots were floated to segregate soil particles from root tissues. The washed roots were dried and weighed. Aliquots of roots were burned in a muffle furnace to determine their ash content. Root biomass is expressed in grams per $m^2$ with ash weights subtracted from the total dry weight. Belowground biomass was sampled only at the beginning and at the end of the spring growing seasons.

#### Results and Discussion

The community consisted of short-statured sagebrush shrubs, *Artemisia tridentata,* widely scattered in an understory layer dominated by perennial bunchgrasses, especially bluebunch wheatgrass, *Agropyron spicatum.* Other perennial bunchgrasses were *Poa sandbergii, Poa cusickii,* and *Stipa thurberiana.* Semi-woody half shrubs were important in the herb layer, especially *Erigeron filifolius, Phlox longifolia,* and *Antennaria dimorpha.* Perennial forbs were represented by scattered individuals of *Lomatium macrocarpum, Lupinus laxiflorus, Astragalus purshii, Brodiaea douglasii, Calochortus macrocarpus,* and others. Annual grasses and forbs were minor constituents of the community

and were represented by *Draba verna, Microsteris gracilis, Plantago patagonica, Vulpia octoflora,* and *Descurainea pinnata.*

At the beginning of the spring growing season in each of the four study years, shoot biomass of herbs ranged between 8 and 18 g per $m^2$, indicating fall and winter growth (Table 1). Live shoot biomass peaked in late May or early June and ranged from 50-69 g per $m^2$ over the 4-year period. The perennial grasses dominated shoot biomass at all sampling times (Fig. 1). Seventy-seven percent of the aboveground herb biomass was contributed by perennial grasses, half-shrubs contributed 16 percent, and perennial forbs contributed 5 percent. Annuals, mostly six weeks' fescue, *Vulpia octoflora,* contributed less than 2 percent.

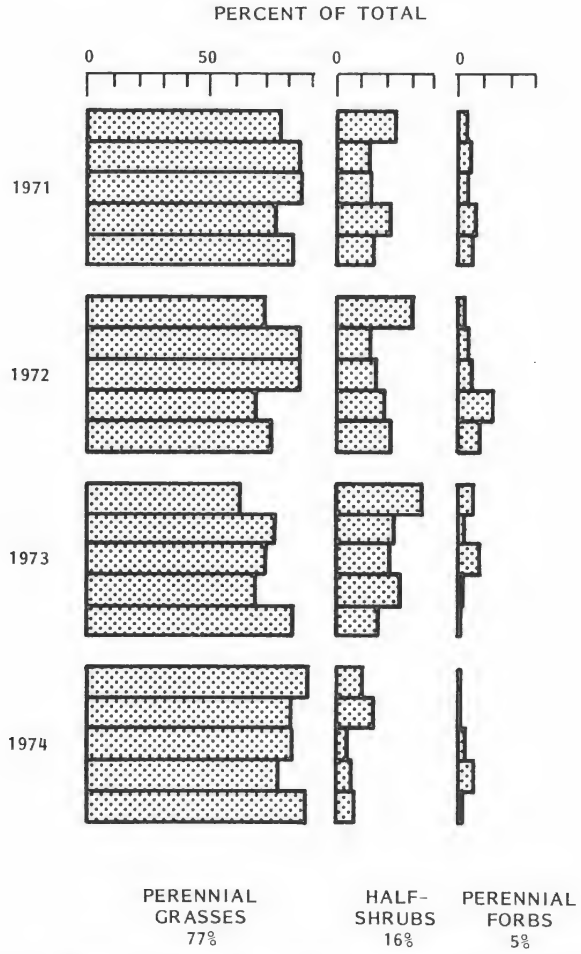


Figure 1. Percentages of perennial grasses, half-shrubs, and perennial forbs in a sagebrush-bunchgrass community at five harvest periods in each of four consecutive years, 1971-1974.

TABLE 1. Dry weights of live herbaceous shoots (g per m² ± SE) in a sagebrush-bunchgrass community in the years 1971-1974.

| | Mar 22 | Apr 8 | Apr 28 | May 24 | Jun 15 |
|---|---|---|---|---|---|
| | | | ——1971—— | | |
| Perennial grasses | 12±1.0 | 20±1.6 | 40±4.4 | 46±1.5 | 45±6.5 |
| Perennial forbs | 0.37±0.14 | 0.78±0.21 | 1.2±0.40 | 3.3±1.3 | 2.1±0.85 |
| Annual grasses | 0.03±0.03 | 0.05±0.03 | 0.43±0.22 | 0.23±0.07 | 0 |
| Annual forbs | 0 | 0.01±0.01 | 0 | 0 | 0 |
| Half-shrubs | 3.6±0.91 | 2.8±0.91 | 6.1±2.2 | 13±4.1 | 8.0±0.93 |
| Total herbs | 16±1.7 | 24±2.4 | 48±5.0 | 63±4.3 | 56±5.7 |
| | Mar6 | Mar 28 | Apr 17 | May 8 | May 30 |
| | | | ——1972—— | | |
| Perennial grasses | 6.1±0.57 | 21±2.2 | 26±2.8 | 28±5.6 | 46±7.4 |
| Perennial forbs | 0.16±0.05 | 0.55±0.15 | 1.1±0.34 | 3.1±1.7 | 4.9±2.4 |
| Annual grasses | 0 | Trace | 0.17±0.05 | 1.1±0.21 | 0 |
| Annual forbs | 0 | 0.06±0.03 | Trace | Trace | Trace |
| Half-shrubs | 2.6±0.94 | 2.9±0.64 | 4.2±1.6 | 7.6±2.6 | 14±6.3 |
| Total herbs | 8.8±0.97 | 25±2.2 | 31±3.4 | 42±5.9 | 65±3.6 |
| | Mar 19 | Apr 9 | Apr 30 | May 21 | Jun 11 |
| | | | ——1973—— | | |
| Perennial grasses | 11±1.3 | 27±3.1 | 36±4.5 | 28±5.3 | 41±6.0 |
| Perennial forbs | 1.1±0.44 | 0.90±0.67 | 4.1±1.8 | 0.73±0.02 | Trace |
| Annual grasses | 0 | 0.21±0.10 | 0.32±0.10 | 0 | 0 |
| Annual forbs | Trace | 0.07±0.02 | 0.11±0.10 | 0 | 0 |
| Half-shrubs | 6.2±2.1 | 8.2±3.3 | 11±4.9 | 11±4.4 | 8.6±3.6 |
| Total herbs | 18±1.8 | 36±4.6 | 51±7.2 | 41±8.0 | 50±5.2 |
| | Feb 26 | Mar 25 | Apr 15 | May 8 | Jun 6 |
| | | | ——1974—— | | |
| Perennial grasses | 15±2.2 | 21±2.0 | 41±4.1 | 54±7.7 | 54±11 |
| Perennial forbs | 0.15±0.08 | 0.25±0.06 | 1.6±1.0 | 4.5±3.6 | 2.1±1.2 |
| Annual grasses | Trace | 0.09±0.06 | 2.4±0.40 | 4.8±0.75 | 0 |
| Annual forbs | 0.16±0.04 | 0.94±0.25 | 2.1±0.54 | 1.4±0.09 | 0.94±0.91 |
| Half-shrubs | 1.7±0.85 | 4.1±1.9 | 2.6±1.4 | 4.2±2.0 | 3.9±2.2 |
| Total herbs | 17±2.1 | 26±2.1 | 50±1.4 | 69±9.3 | 61±9.0 |

TABLE 2. Dry weights (g per m² dry wt ± SE) of grass crowns, standing dead plants and litter in a sagebrush-bunchgrass community in the years 1971-1974

| | 22 Mar | 8 Apr | 28 Apr | 24 May | 15 Jun | Avg. | Total Wt. |
|---|---|---|---|---|---|---|---|
| | | | ——1971—— | | | | |
| Crowns | 39± 9.0 | 43± 7.7 | 72±12 | 59± 8.0 | 56± 8.5 | 54 | |
| Standing dead | 90± 9.6 | 81± 9.5 | 100±15 | 80± 9.1 | 72±10 | 85 | 300 |
| Litter | M | M | M | 158±17 | 165±16 | 161 | |
| | 7 Mar | 28 Mar | 17 Apr | 10 May | 31 May | | |
| | | | ——1972—— | | | | |
| Crowns | 96± 9.3 | 106±12 | 69±81 | 81± 8.0 | 123±11 | 95 | |
| Standing dead | 80±12 | 78±15 | 63±12 | 50±93 | 75± 7.7 | 69 | 282 |
| Litter | 101±13 | 123±14 | 113±15 | 98±11 | 156± 9.6 | 118 | |
| | 19 Mar | 9 Apr | 30 Apr | 21 May | 11 Jun | | |
| | | | ——1973—— | | | | |
| Crowns | 69± 7.1 | 101±10 | 98±10 | 93±18 | 132±16 | 99 | |
| Standing dead | 96±18 | 81± 8.9 | 100±17 | 78±15 | 114±17 | 94 | 327 |
| Litter | 125±24 | 117±14 | 112±18 | 139±15 | 175±21 | 134 | |
| | 26 Feb | 25 Mar | 15 Apr | 8 May | 6 Jun | | |
| | | | ——1974—— | | | | |
| Crowns | 81±13 | 101±11 | 95± 8.8 | 86±17 | 83± 9.5 | 89 | |
| Standing dead | 105±20 | 71± 5.5 | 94±13 | 61±12 | 73±13 | 81 | 293 |
| Litter | 152±27 | 110±13 | 123±16 | 111±18 | 117±20 | 123 | |

M = missing datum

Grass crowns, standing dead herbaceous material, and the litter components of the community showed no consistent change in biomass from the beginning to the end of the spring growing season (Table 2). Litter averaged 134, grass crowns, 84, and standing dead herbage, 82, g per $m^2$. Sagebrush shrubs contributed 70 g per $m^2$. Wood litter was the greatest single contributor to woody biomass at 57 g per $m^2$.

About 25 percent of the root biomass was in the upper decimeter of soil profile and 41 percent in the upper 2 decimeters (Table 4). At the beginning of the spring growing season root biomass in the upper 8 decimeters was 880 g per $m^2$, and 114 g per $m^2$ at the end of the spring growing season.

TABLE 3. Dry weights (g per $m^2$ ± SE) of sagebrush shrubs in a sagebrush-bunchgrass community in the years 1971-1973.

| | Mar 22 | Apr 8 | Apr 28 | May 24 | June 15 | Avg. | Total |
|---|---|---|---|---|---|---|---|
| | | | ——1971—— | | | | |
| Leaves | 4.4± 1.2 | 4.3± 1.3 | 2.7± 0.9 | 11 ± 5.0 | 5.7± 1.7 | 5.6 | |
| Livewood | 46 ±15 | 38 ±11 | 11 ± 2 | 47 ±22 | 36 ±12 | 36 | 148 |
| Deadwood | 50 ±17 | 18 ± 6 | 35 ± 7 | 57 ±17 | 60 ±15 | 44 | |
| Wood Litter | 41 ±13 | 74 ±33 | 45 ±13 | 60 ±17 | 88 ±28 | 62 | |
| | Mar 6 | Mar 28 | Apr 17 | May 8 | May 30 | | |
| | | | ——1972—— | | | | |
| Leaves | 1.4± 1.1 | 1.0± 0.8 | 28 ±21 | 51 ±50 | 12 ±12 | 19 | |
| Livewood | 20 ±14 | 3.8± 2.3 | 12 ± 9.3 | 12 ± 8.8 | 0.6± 0.6 | 9.7 | 100 |
| Deadwood | 36 ±25 | 0 | 22 ±12 | 0 | 0 | 12 | |
| Wood Litter | 68 ±25 | 97 ±32 | 23 ± 5 | 48 ±18 | 52 ±20 | 58 | |
| | Mar 19 | Apr 9 | Apr 30 | May 21 | Jun 11 | | |
| | | | ——1973—— | | | | |
| Leaves | 5.8± 3.0 | 1.5± 1.4 | 3.9± 3.0 | 8.1± 3.0 | 5.4± 5.4 | 4.9 | |
| Livewood | 113 ±94 | 2.4± 2.3 | 9.3± 6.8 | 33 ±17 | 47 ±47 | 41 | 132 |
| Deadwood | 17 ± 7.6 | 15 ±12 | 42 ±22 | 42 ±37 | 69 ±47 | 37 | |
| Wood Litter | 35 ±16 | 97 ±39 | 47 ±21 | 36 ±16 | 30 ± 9 | 49 | |

TABLE 4. Dry weight of roots (g per $m^2$ ± SE) in a sagebrush-bunchgrass community in the years 1972-1974.

| Soil Depth dm | 1972 6 Mar | 1973 19 Mar | 1974 26 Feb | Avg. | % |
|---|---|---|---|---|---|
| 0-1 | 155±15 | 274±31 | 297±40 | 242 | 27 |
| 1-2 | 115±28 | 117± 5 | 142±17 | 125 | 14 |
| 2-3 | 101±26 | 103± 2 | 95±16 | 100 | 11 |
| 3-4 | 113±21 | 108± 3 | 95±10 | 105 | 12 |
| 4-5 | 101±13 | 100± 4 | 81± 8 | 94 | 11 |
| 5-6 | 74±12 | 95± 3 | 91± 7 | 87 | 10 |
| 6-7 | 57± 6 | 81± 3 | 69± 7 | 69 | 8 |
| 7-8 | 58± 7 | 66± 3 | 53± 6 | 59 | 7 |
| Total | 774 | 944 | 923 | 881 | 100 |
| | 30 May | 11 Jun | 8 May | | |
| 0-1 | 282±32 | 359±85 | 216±35 | 286 | 25 |
| 1-2 | 229±25 | 193±26 | 143±17 | 188 | 16 |
| 2-3 | 167±17 | 150±20 | 98± 9 | 139 | 12 |
| 3-4 | 166±22 | 135±11 | 85± 4 | 127 | 11 |
| 4-5 | 170±18 | 121±10 | 87± 7 | 126 | 11 |
| 5-6 | 166±16 | 108± 7 | 67± 7 | 114 | 10 |
| 6-7 | 126±12 | 92± 8 | 58± 8 | 92 | 8 |
| 7-8 | 118±14 | 68± 5 | 41± 6 | 76 | 7 |
| Total | 1424 | 1226 | 795 | 1147 | 100 |

Aboveground biomass at peak production in the spring was 490 g per $m^2$ and belowground biomass was 1150 (Table 5). Total biomass was 1600 g per $m^2$. Aboveground production in the sagebrush-bunchgrass community was at the low end of the scale of production for other kinds of grass-dominated communities in semi-arid regions of western North America (Table 6).

It was expected that annual herbage production would show a direct relationship between high and low precipitation years. High precipitation years were expected to show high plant production and low years, low production. The relationship between precipitation (Oct.-May) and peak herbage production is shown below.

| | 1971 | 1972 | 1973 | 1974 |
|---|---|---|---|---|
| Precipitation (cm) | 21.4 | 17.4 | 12.9 | 36.2 |
| Production (g per $m^2$) | 63 | 65 | 50 | 69 |
| Efficiency (g per $m^2$/ppt cm) | 2.9 | 3.7 | 3.9 | 1.9 |

TABLE 5. Summary of biomass components in a sagebrush-bunchgrass community.

| TOTAL BIOMASS 1600 g per $m^2$ | | | |
|---|---|---|---|
| ABOVEGROUND BIOMASS 490 g per $m^2$ | | | |
| HERBS | | SAGEBRUSH | |
| Liveshoots | 62 | Leaves | 10 |
| Standing dead | 82 | Livewood | 29 |
| Grass crowns | 84 | Deadwood | 31 |
| Litter | 134 | Wood litter | 57 |
| Total | 360 | Total | 130 |
| BELOWGROUND BIOMASS 1150 g per $m^2$ | | | |

TABLE 6. Live aboveground biomass in steppe communities in the western United States (Lauenroth 1979).

| <100 g/$m^2$ | | 101-200 g/$m^2$ | | 201-300 g/$m^2$ | |
|---|---|---|---|---|---|
| Albion, MT | 42 | *SE Washington | 104 | Bismark, ND | 203 |
| Sundance, WY | 76 | *SE Washington | 115 | San Joaquin, CA | 224 |
| Ardmore, SD | 86 | Las Cruces, NM | 115 | Dickinson, ND | 224 |
| *Richland, WA | 82 | Sydney, MT | 122 | Hopland, CA | 228 |
| **Richland, WA | 70 | ***Rexburg, ID | 123 | St. Lanatius, MT | 230 |
| | — | Newtown, ND | 144 | Hays, KN | 234 |
| Average | 71 | Santa Rita, NM | 144 | Long Valley, SD | 250 |
| | | Nunn, CO | 145 | Amarillo, TX | 257 |
| | | San Jose, CA | 166 | Norman, OK | 265 |
| | | | | Throckmorton, TX | 280 |
| | | Average | 120 | Cottonwood, SD | 282 |
| | | | | Boulder, CO | 298 |
| | | | | Average | 248 |

| 301-400 g/$m^2$ | | >400 g/$m^2$ | |
|---|---|---|---|
| Vermillion, SD | 353 | Paskuska, OK | 567 |
| Cresco, IA | 369 | Columbia, MO | 634 |
| Urbana, IL | 373 | | |
| Manhatten, KN | 387 | Average | 600 |
| Average | 370 | | |

*Daubenmire 1970
**This study
***Pearson 1965

These data show that the lowest precipitation year, 1973, had the lowest production, and that the high precipitation year, 1974, had the greatest productivity. However, there was relatively little difference in production in the years 1971, 1972, and 1974. Overall the variation in production was not as great as the variation in precipitation. This indicates that the sagebrush-bunchgrass community had some level of stability over a reasonably broad range of precipitation. The data also show that the community efficiency ratio is greatest during low precipitation years and least in high precipitation years. This suggests that water losses by physical processes (i.e., runoff, infiltration, evaporation) are greatest during high precipitation years. The fundamental role of sagebrush shrubs in sagebrush-bunchgrass communities is a subject of on-going ecological research. Sagebrush is virtually the only non-aestivating plant in the shrubsteppe community in summer. It has the capacity to use soil water that has penetrated below the rooting depth of grasses (Daubenmire 1970). Mineral nutrients from deep in the soil profile can be brought to the surface by root uptake, deposited in leaves and then returned to the soil via leaf fall (Mack 1977). These sagebrush processed nutrients are eventually available for use by grasses and forbs as they are released from the dead sagebrush leaves by weathering and microbial decomposition processes. Sagebrush wood acts as a sink for nutrients because it is slow to decompose. Dead herbaceous plant tissues decompose more quickly than sagebrush wood but the rate of decomposition has not been adequately studied (Comanor and Staffeldt 1978).

Sagebrush provides nesting sites for small passerine birds that otherwise would not nest in the community (McAdoo and Klebenow 1979). Sagebrush also provides forage for jackrabbits, *Lepus californicus*, mule deer, *Odocoileus hemionus*, and sagegrouse, *Centrocercus urophasianus*. Sagebrush is not palatable to livestock, and most rangeland research has been aimed at developing cost-effective ways of eradicating sagebrush shrubs to enhance the growth and productivity of livestock palatable grasses (Britton and Ralphs 1979, Evans *et al.* 1979).

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# Herbaceous Response Following Prescribed Burning and Seeding of Elk Range in Idaho

## Abstract

The effects of spring-burning and seeding on herbaceous vegetation were evaluated on brush covered slopes in the grand fir/boxwood (*Abies grandis/Pachistima myrsinites*) habitat type. The objective of the burn was to improve winter-spring forage for elk (*Cervus elaphus nelsoni*). There was a significant increase in forb production during the second growing season following prescribed burning. After four growing seasons, broadcast-seeded grasses, primarily orchard grass (*Dactylis glomerata*), were the only species producing substantial forage in excess of pre-burn amounts. A mixture of several grasses is recommended for broadcast-seeding immediately after burning in similar habitat types when the primary purpose is to increase herbaceous forage for spring utilization by elk.

## Introduction

Prescribed burning has been used to modify seral brushfields on elk winter range in northern Idaho since the early 1960s (Leege 1969). Studies have focused on the response of shrub species to burning during spring and fall months (Leege and Hickey 1971, Asherin 1976) and also to repeated burns (Leege 1979). In recent years it became apparent that many winter ranges also serve as spring ranges, providing grasses and forbs as forage after the snow recedes in April and May. Spring is a critical period for cow elk because the energy demands during the last stages of gestation can become excessive if adequate amounts of good quality forage are not available (Thorne *et al.* 1976).

In this study we documented the response of herbaceous species to spring burning; specifically:

1. Changes in occurrence and production of on-site herbage; and
2. Establishment, survival, and growth of seven grass and one forb species seeded after burning.

## Study Area

The study area was in the Clearwater National Forest at the mouth of Noseum Creek, a tributary of the Lochsa River in north-central Idaho. The aspect was generally south-facing, elevation 700 m, and slope ranged from 40 to 80 percent. Annual precipitation averaged about 100 cm. The summer months are normally hot and dry. The site was classified as a grand fir/boxwood habitat type according to descriptions by Daubenmire

and Daubenmire (1968). Soil originated from granitic parent material and was coarse in texture. Wild fires in 1919 and 1934 burned the area and existing seral vegetation consisted primarily of shrubs dominated by redstem ceanothus (*Ceanothls sanguineus*), scouler willow (*Salix scouleriana*), serviceberry (*Amelanchier alnifolia*), syringa (*Philadelphus lewisii*), oceanspray (*Holodiscus discolor*), snowberry (*Symphoricarpos albus*), and spiraea (*Spiraea betulifolia*). No livestock grazing occurred either before or during the study. However, some elk and mule deer (*Odocoileus hemionus*) used the area during the winter and spring months.

#### Methods

We evaluated two different treatments; burn-only, and burn-and seed. One transect was established in each treatment and on a control area which was not burned or seeded. Transects were about 15 m apart and parallel with each other. Ten circular plots, 61 cm in diameter, were placed at 10 m intervals along each transect. Plot centers were marked with metal reinforcing rods 60 cm long. All plots were established and the vegetation measured on 3 July 1974 (pre-burn); post-burn measurements were made on 9 August 1975, 17 July 1976, and 8 July 1978. Plant development and succulence appeared similar for each of the measurement periods, except in 1975 when the vegetation was more advanced phenologically. At each plot, percentage bare ground, litter, herbaceous vegetation, and rock was estimated. Leaves on woody species were not included in ground cover estimates. For each plot we recorded all grass, sedge, and forb species present, counted all shrub seedlings by species, and estimated herbage production for each species that weighed five or more grams, and total production. Production estimates were improved by clipping and weighing individual and groups of plants of the same species adjacent to the plots. Plant nomenclature follows Hitchcock and Cronquist (1973).

The two treatment areas (transects no. 1 and 3) were burned with a headfire on 14 May 1975 when all species were actively growing following winter dormancy. Weather information taken on-site at 1300 hours was: temperature 28°C (82°F), relative humidity 25 percent, and wind negligible. The fire was ignited on the slope below the transects and burned briskly and completely over a 2 ha area where the treatment plots were located. On 15 May 1975 we used a cyclone seeder to broadcast seeds of the following species on transect no. 3: Primar slender wheatgrass (*Agropyron trachycaulum*), Nordan crested wheatgrass (*Agropyron cristatum*), bulbous bluegrass (*Poa bulbosa*), Latar orchard grass (*Dactylis glomerata*), Durar hard fescue (*Festuca ovina duriuscula*), Alkar tall wheatgrass (*Agropyron elongatum*), yellow sweetclover (*Melilotus officinalis*), and Sherman big bluegrass (*Poa ampla*). These species were selected based on recommendations made by seeding specialists at Washington State University and the Soil Conservation Service. Approximately equal volumes of seed for each species were mixed and broadcast seeded at about 7 kg/ha (6 lb/acre). An analysis of variance and Duncan's new multiple range test (Steel and Torrie 1960) were used to detect changes in herbage production among treatments. Test results were considered significant if $P<0.05$.

#### Results

Pre-burn measurements of production indicated important, although not significant,

differences among the transects. These differences may have occurred because the control area (T2) was on a slightly more xeric site than the treated areas.

### Ground Cover

Bare ground increased during the first growing season following both burning treatments (Table 1). The increase, however, was slight and of short duration. Differences in the combination of herbaceous and litter cover among the four years measured were minimal. We observed no evidence that soil erosion was accelerated after burning.

TABLE 1. Ground cover (%) on two treatment areas and a control area before and after the 1st, 2nd, and 4th growing season following burning.

| Ground cover (%) | Before | 1st year | 2nd year | 4th year |
|---|---|---|---|---|
| | | Control (T2) | | |
| Bare ground | 3 | 1 | 3 | 3 |
| Herbaceous and litter | 96 | 97 | 95 | 96 |
| Rock | 1 | 2 | 2 | 1 |
| Total | 100 | 100 | 100 | 100 |
| | | Burn Only (T1) | | |
| Bare ground | 7 | 10 | 4 | 4 |
| Herbaceous and litter | 93 | 90 | 96 | 96 |
| Rock | 0 | 0 | 0 | 0 |
| Total | 100 | 100 | 100 | 100 |
| | | Burn and Seed (T3) | | |
| Bare ground | 1 | 6 | 9 | 4 |
| Herbaceous and litter | 99 | 93 | 90 | 96 |
| Rock | 0 | 1 | 1 | 0 |
| Total | 100 | 100 | 100 | 100 |

### Changes in Species Composition

Forty non-seeded species were recorded on the three transects. Seven of these species tended to increase in frequency of occurrence following burning, eight decreased, and the remainder either indicated no trend or were present in insufficient quantity to provide a reliable indication (Table 2). Of the seven species that increased, three were very evident for the first two years after burning but were disappearing by the fourth year. Two of these were biennials, evening primrose (*Oenothera strigosa*) and mullein (*Verbascum thapsus*), and the third was a perennial, mountain hollyhock (*Iliamna rivularis*).

Species of *Carex*, primarily elk sedge (*C. geyeri*) and Ross' sedge (*C. rossii*) also increased. Frequency of this genus almost doubled on both treatment areas while it remained essentially stable on the control area. Penstemon (*Penstemon wilcoxii*) increased on both treatment areas also. Sourdock (*Rumex acetosella*) increased greatly on the burn-only area but did not occur on the burn-and-seed area. Thistle (*Cirsium* sp.) increased slightly on the burn-and-seed area.

TABLE 2. Frequency of occurrence (F), and green-weight production (P) on two treatment areas and a control area before and after the 1st, 2nd, and 4th growing season following burning.

| Species | Control (T2) | | | | | | | | Burn Only (T1) | | | | | | | | Burn and Seed (T3) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before | | 1st | | 2nd | | 4th | | Before | | 1st | | 2nd | | 4th | | Before | | 1st | | 2nd | | 4th | |
| | F[a] | P[b] | F | P | F | P | F | P | F | P | F | P | F | P | F | P | F | P | F | P | F | P | F | P |
| FORBS | | | | | | | | | | | | | | | | | | | | | | | | |
| **Achillea millifolium** | 2 | | 2 | (10) | 1 | (30) | 3 | | | | | | 1 | | | | 2 | (15) | 2 | (15) | 2 | (65) | 2 | |
| **Anemone piperi** | 3 | | 3 | | 4 | | 4 | | 7 | | | | 7 | | 7 | | 4 | | 1 | | 7 | | 7 | |
| **Arenaria macrophylla** | 5 | | 7 | | 7 | | 8 | | 9 | | 4 | | 6 | | 4 | | 6 | | 4 | | 2 | | 3 | |
| **Arenaria serpyllifolia** | 1 | | | | | | | | 1 | | | | | | 2 | | | | | | | | | |
| **Campanula rotundifolia** | | | | | 2 | | | | | | | | | | | | | | | | | | | |
| **Circium** sp. | | | | | | | | | | | | | | | | | | | 1 | | 1 | (200) | | |
| **Clarkia pulchella** | 3 | | | | | | 2 | | | | | | | | | | | | | | | | | |
| **Collinsia parviflora** | 1 | | | | 7 | | 2 | | 2 | | | | 2 | | 2 | | | | | | 4 | | 1 | |
| **Collomia** spp. | 1 | | 1 | | 3 | | 1 | | | | | | | | | | 1 | | | | | | | |
| **Disporum trachycarpum** | | | | | | | 1 | | | | | | 1 | | 1 | (25) | 1 | | | | 1 | | 1 | |
| **Epilobium angustifolium** | | | | | | | | | 1 | | 1 | | | | 2 | | | | | | | | | |
| **Epilobium paniculatum** | 1 | | | | 1 | | 1 | | | | | | | | 1 | | 1 | | | | | | | |
| **Erythronium grandiflorum** | | | | | | | | | | | | | | | | | 1 | | | | | | | |
| **Fragaria vesca** | 5 | | 5 | | 7 | | 8 | (5) | 7 | | 2 | | 4 | | 6 | | 5 | | 1 | | 3 | | 5 | |
| **Galium triflorum** | 4 | | | | 3 | | 4 | | 3 | | 2 | | 1 | | 1 | | 6 | | | | | | 2 | |
| **Hypericum perforatum** | 5 | (50) | 5 | (20) | 7 | (155) | 3 | | 5 | (10) | 6 | (25) | 6 | (200) | 4 | | 5 | | 6 | (20) | 7 | (325) | 7 | |
| **Iliamna rivularis** | | | | | | | | | | | 1 | | | | | | | | 4 | | 2 | | 1 | |
| **Lathyrus nevadensis** | 2 | | | | 1 | | 2 | | | | | | | | | | 1 | | | | 1 | | | |
| **Madia** sp. | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | |
| *Melilotus officinalis | | | | | | | | | | | | | | | | | | | 3 | | 4 | | | |
| **Mitella stauropetala** | | | 1 | | 1 | | 1 | (15) | 1 | | 1 | | | | 1 | | 4 | | 1 | | 1 | | 1 | |
| **Oenothera strigosa** | | | | | | | | | | | 3 | (45) | 4 | (750) | 4 | | | | 3 | (60) | 3 | (1250) | 5 | |
| **Penstemon wilcoxii** | 3 | | 3 | | 4 | | 4 | (5) | 1 | (30) | 4 | (5) | 5 | (35) | 4 | (25) | 4 | | 5 | | 6 | (25) | 7 | (10) |
| **Phacelia heterophylla** | | | | | | | | | | | | | | | | | | | 1 | | 1 | | | |
| **Polygonum douglassi** | | | | | 3 | | 2 | | | | | | 3 | | 1 | | | | | | 1 | | | |
| **Pteridium aquilinum** | | | | | | | | | 3 | (690) | 3 | (630) | 3 | (860) | 3 | (1000) | 3 | (415) | 2 | (300) | 3 | (855) | 4 | (755) |
| **Rumex acetosella** | 1 | | 2 | | 3 | | 3 | (20) | | | | | 5 | | 4 | (10) | | | | | | | | |

TABLE 2. (Continued)

| Species | Control (T2) Before F[a] | P[b] | 1st F | P | 2nd F | P | 4th F | P | Burn Only (T1) Before F | P | 1st F | P | 2nd F | P | 4th F | P | Burn and Seed (T3) Before F | P | 1st F | P | 2nd F | P | 4th F | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Smilacina stellata** | 4 | | 4 | (10) | 4 | (15) | 6 | (85) | 7 | (65) | | | 5 | | 5 | (35) | 8 | (35) | 1 | | 7 | (10) | 8 | (55) |
| **Solidago canadensis** | 1 | (15) | 1 | (10) | 1 | (10) | 1 | | 1 | (40) | 1 | (20) | 1 | (25) | 1 | (15) | | | | | 1 | | 2 | |
| **Taraxacum officinale** | 1 | | 1 | | 2 | | 1 | | 1 | | | | 1 | | | | | | | | | | | |
| **Tragopogon dubius** | 1 | | | | | | | | | | | | | | 1 | | | | | | | | | |
| **Verbascum thapsus** | | | | | | | 1 | | | | 6 | (110) | 6 | (850) | | | | | | | | | | |
| **Vicia** sp. | | | | | 1 | | 2 | | | | | | | | | | | | | | | | | |
| GRASSES AND SEDGES | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Agropyron trachycaulum** | | | | | | | | | | | | | | | | | | | | | | | 2 | (35) |
| ***Agropyron** spp. | | | | | | | | | | | | | | | | | | | 7 | | 2 | | | |
| **Bromus carinatus** | | | 1 | | 1 | | 1 | | 3 | | 1 | | 1 | | | | 4 | | 2 | | | | | |
| **Bromus tectorum** | 1 | | | | | | | | | | | | | | | | 1 | | | | | | | |
| **Carex** spp. | 4 | (25) | 4 | (15) | 5 | (15) | 5 | (30) | 5 | | 5 | | 9 | | 9 | (10) | 5 | | 4 | | 10 | | 10 | |
| ***Dactylis glomerata** | | | | | | | | | | | | | | | | | | | 5 | | 6 | (25) | 8 | (730) |
| **Elymus glaucus** | 3 | | 3 | | 2 | | 2 | | | | | | | | 1 | | 4 | | 1 | | | | | |
| **Festuca** spp. | | | | | | | | | | | | | | | | | | | 1 | | 1 | | | |
| **Festuca occidentalis** | 1 | | 1 | | | | 3 | | | | | | | | | | | | | | | | 1 | |
| ***Festuca ovina** | | | | | | | | | | | | | | | | | | | | | | | 1 | (5) |
| **Panicum** sp. | | | | | | | | | | | 2 | | 2 | | 2 | | | | | | | | | |
| **Poa** sp. | | | | | | | | | | | | | | | | | | | | | 2 | | | |
| ***Poa ampla** | | | | | | | | | | | | | | | | | | | | | | | 3 | |
| ***Poa bulbosa** | | | | | | | | | | | | | | | | | | | 2 | | | | | |
| **Poa pratensis** | 4 | | 4 | | 5 | | 5 | (55) | 2 | | 3 | | 3 | | 3 | | 1 | | 1 | | | | 2 | |
| Misc. production | (165) | | (60) | | (90) | | (65) | | (170) | | (40) | | (60) | | (75) | | (185) | | (35) | | (55) | | (80) | |
| Forb production | (65) | | (50) | | (210) | | (130) | | (835) | | (835) | | (2720) | | (1110) | | (465) | | (395) | | (2730) | | (855) | |
| Grass production | (25) | | (15) | | (15) | | (85) | | (0) | | (0) | | (0) | | (10) | | (0) | | (0) | | (25) | | (735) | |
| Total production | (255) | | (125) | | (315) | | (280) | | (1005) | | (875) | | (2780) | | (1195) | | (650) | | (430) | | (2810) | | (1670) | |

[a]Frequency = number of plots in which occurred (10 possible).
[b]Green weight production in grams.
*Seeded species.

Of the eight species reduced in frequency by the fire, five did not regain their pre-burn densities by the fourth growing season: sandwort (*Arenaria macrophylla*), mountain brome (*Bromus carinatus*), bedstraw (*Galium triflorum*), mitrewort (*Mitella stauropetala*) and blue wildrye (*Elymus glaucus*). Although the frequency of mitrewort was not reduced on the burn-only area, it was reduced dramatically on the burn-and-seed area. Reduced frequency of blue wildrye was noted on only the burn-and-seed area. Competition from the broadcast-seeded species may have contributed to these declines. The other three species, windflower (*Anemone piperi*), strawberry (*Fragaria vesca*), and false Solomon's seal (*Smilacina stellata*) were reduced the first two growing seasons after burning but regained or surpassed pre-burn frequencies by the fourth season.

The distribution of two dominant species on the area appeared to be only slightly affected by burning. Goatweed (*Hypericum perforatum*) occurred on all three study areas and did not show any obvious changes following treatment. Bracken fern (*Pteridium aquilinum*) frequency changes after burning were also minimal.

Of the seeded species, only four were present in the plots during the fourth growing season. Orchard grass was most abundant, occurring in eight of ten plots. Sherman big bluegrass occurred in three plots, Primar slender wheatgrass in two plots, and Durar hard fescue in one plot. Yellow sweet clover was present in four plots in the second year following seeding, but had disappeared by the fourth year.

### Changes in Herbage Production

Pre-treatment production estimates on the control area and burn-and-seed area were only 25 percent and 65 percent, respectively, of the burn-only area (Table 2).

In the first growing season after burning (1975), forage production on both treatment areas and the control area was lower than the previous year even though precipitation was above normal (Tables 2 and 3, Figure 1). This may have been due to differences in measurement dates which resulted in advanced phenology and curing in 1975.

During the second growing season, forage production increased significantly ($P < .05$) from pre-burn measurements on both the burn-only (176 percent) and burn-and-seed (332 percent) areas. The 24 percent increase on the control area was not significant. On the burn-only area most of the production increase was due to evening primrose and mullein, the two biennials which germinated after the fire. The increase on the burn-and-seed area was due primarily to evening primrose, although goatweed and bracken fern production was also high.

During the fourth growing season, total herbaceous production was 157 percent, 19 percent, and 10 percent greater than the pre-burn growing season on the burn-

TABLE 3. Precipitation in centimeters at Fenn Ranger Station[a] during April, May, June and July through the study period. *Data not collected.

| | 1974 | 1975 | 1976 | 1978 | Long term average |
|---|---|---|---|---|---|
| April | 11 | 13 | 8 | 7 | 9 |
| May | 7 | 10 | 7 | * | 9 |
| June | 8 | 9 | 11 | 4 | 8 |
| July | 3 | 4 | 6 | * | 2 |

[a]Fenn Ranger Station is located 35 km SW of the study area at an elevation of 488 m.

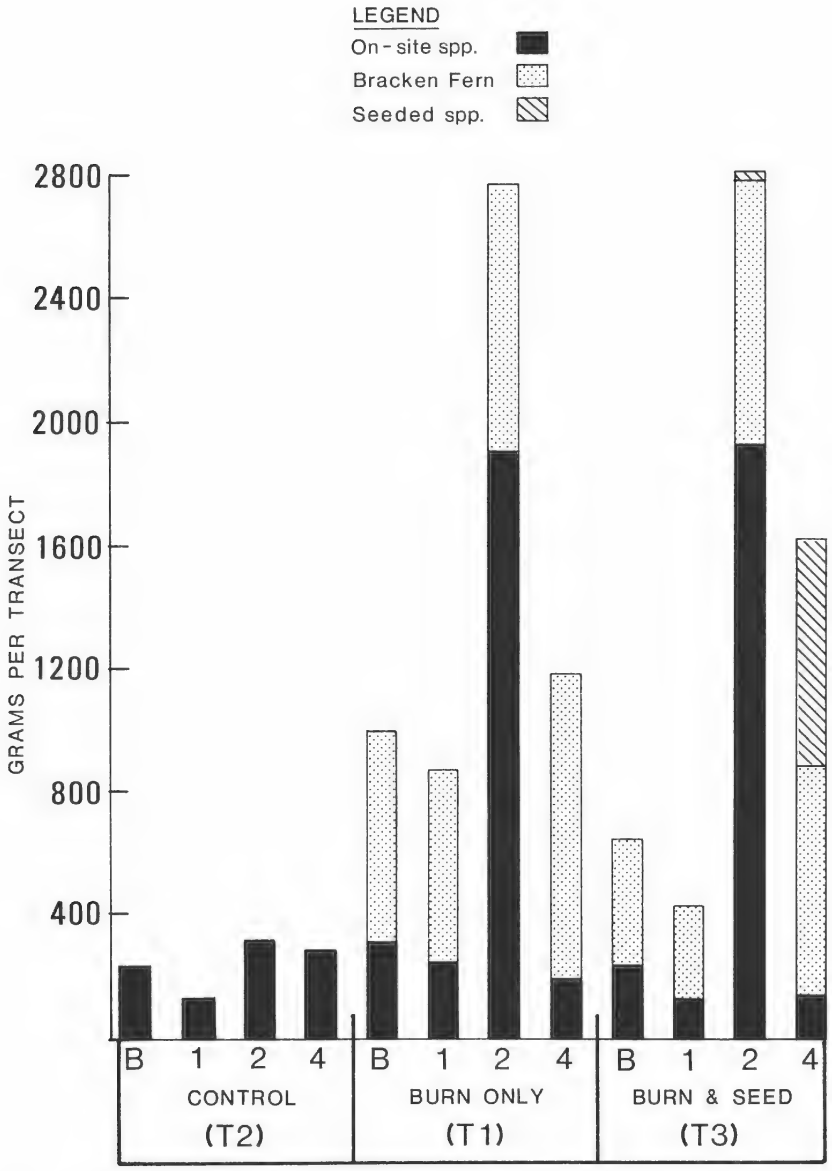


Figure 1. Green herbaceous production wthin plots on three study areas before treatment (B), and after the first (1), second (2) and fourth (4) growing seasons following spring burning.

and-seed, burn-only, and control treatment areas, respectively. Forb production, excluding bracken fern, decreased to approximately pre-burn levels. Production of evening primrose, goatweed, and mullein was substantially reduced during the fourth growing season.

Bracken fern production appeared to be favored by burning and/or the subsequent reduction of shrub overstory. Even though there was some reduction of bracken fern production on the burn-and-seed area from the second to fourth growing season, its production remained 54 percent greater than the pre-burn estimate. Bracken fern production continued to increase on the burn-only area and was 69 percent greater than the pre-burn estimate during the fourth growing season. No bracken fern occurred on the control area.

By the fourth growing season, two seeded species on the burn-and-seed area were established and major contributors to forage production. Orchard grass and slender wheatgrass produced 44 percent and 2 percent, respectively, of total herbage. Big Bluegrass and hard fescue were present but did not contribute any substantial production.

### Shrub Seedling Survival

No shrub seedlings were observed during any year on the control area. On the burn-only area, seedings were found during the second growing season after burning: 20 redstem ceanothus in 4 (of 10) plots; 7 bittercherry (*Prunus emarginata*) in 5 plots. During the fourth growing season, 2 redstem ceanothus seedlings remained in 1 plot and 4 bittercherry were left in 2 plots. On the burn-and-seed transect, 1 redstem ceanothus and 1 bittercherry seedling were found the first growing season after burning. During the second growing season, the normal time for redstem ceanothus seedlings to appear after spring burning (Orme and Leege 1976), 9 plots contained 46 redstem ceanothus, and 4 plots had 5 bittercherry seedings. In the fourth growing season, no redstem ceanothus and 1 bittercherry remained in the plots.

## Discussion

Amount of ground cover provided by live herbaceous material and litter was reduced very little by burning and returned toward original levels at a rapid rate (Table 1). Similar findings were reported by Leege and Schlegel (unpub. rept. W-139-R-4, Study 2, Job 4, Id., 1973) for spring burns on two other Lochsa River study areas.

Spring burning did not cause an important change in species composition among the forbs and grasses. There was an increase in herbage production during the second growing season, primarily because of the maturing of biennials which germinated following the fire. However, by the fourth growing season, biennials had declined considerably and production of on-site species differed only slightly from pre-burn conditions. Two of the forbs which showed a significant increase, mountain hollyhock and evening primrose, are eaten by elk during the spring and summer months (Leege, personal observation), thus their increase after burning, albeit for a short period, may be of some benefit to elk. The sedges (*Carex* spp.) also increased after burning and are known to be important as spring and summer elk forage (Nelson and Leege 1982).

Other major changes following treatment involved the seeded grasses. Orchard grass was the most successfully established and productive seeded species. It occurred on almost all seeded plots and made a substantial contribution to total production during the fourth growing season. This species is preferred by elk during spring and

summer months (Nelson and Leege 1982). Other seeded species showing some success in becoming established after four years were slender wheatgrass, hard fescue and big bluegrass.

The eight species sowed in this study were also broadcast seeded on unstable south-facing slopes along Bee Creek and near Beaver Flat along the Lochsa River, on 5 November 1974 (Leege and Godbolt, unpublished data). On 8 July 1978 the same four species successful in this study (orchard grass, hard fescue, big bluegrass, and slender wheatgrass) were growing well and producing seedheads on the Beaver Flat area. No plants of the other four species were located. None of the eight species survived on the Bee Creek area, possibly because the slopes were in excess of 80 percent (about 60 percent on Beaver Flat) and the soil very loose and sandy. These two study areas had not been burned just prior to seeding; however, there was very little woody overstory and only minimal competition from herbaceous vegetation because of the xeric nature of the sites.

Favorable results with big bluegrass and orchard grass were also reported by Anderson and Brooks (1975) when they broadcast-seeded an area burned by wildfire in Oregon. Another species that did well in Oregon was intermediate wheatgrass (*Agropyron intermedium*), which might be seeded successfully in northern Idaho. Big bluegrass was broadcast seeded with greater success than six wheatgrasses on dry slopes in southeastern Washington, probably because of its small seed size and good contact with the soil (Nelson *et al.* 1970).

Fall planting is normally more successful than spring planting since moisture is usually available for a longer period after germination (Plummer *et al.* 1968). However, our results indicated that planting as late as mid-May can be successful with four of the eight species tested when May, June, and July precipitation is above normal (Table 3).

Since these ranges are usually dominated by shrubs, it is expected that shrub canopies will eventually intercept a greater amount of sunlight and herbaceous production will decrease. Therefore, seeding after burning to increase herbage production is expected to have relatively short term (10-15 year) benefits.

One of the primary reasons for burning winter ranges is to increase browse production of redstem ceanothus (Orme and Leege 1976). It should be recognized that abundant grass seedlings will compete with those of redstem ceanothus. Even though sample sizes were small, our results suggest that both redstem ceanothus and bittercherry seedlings had lower survival on the area where grasses were seeded.

#### Recommendations

1. If the management objective is to improve the quantity and quality of spring elk forage, we recommend broadcast burning followed by seeding a mixture of 25 percent orchard grass, 25 percent hard fescue, 33 percent slender wheatgrass, and 17 percent big bluegrass at 13.5 kg/ha (12 lb/acre).

2. If the primary management objective is to increase shrub density on elk winter range with prescribed burning, do not seed grass.

3. Because moisture for germination and survival of grass seed is more dependable in the fall and winter months, fall burning and seeding is preferable to spring treatment when feasible. In all cases, seed should be applied soon after the ashes have cooled.

4. Since seeded species on our study area did not become productive until at least the third growing season, defer domestic livestock grazing for at least two years after seeding.

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# Food Habits of Nesting Great Blue Herons at Heyburn State Park, Idaho

## Abstracts

The food habits of nesting great blue herons (*Ardea herodias*) were studied in 1977 and 1978 at Heyburn State Park. Brown bullheads (*Ictalurus nebulosus*) and tench (*Tinca tinca*) provided the main nutritional needs in this heronry, comprising 75 percent and 60 percent of the total sampled biomass in 1977 and 1978, respectively. The meadow vole (*Microtus pennsylvanicus*) was also an important diet component, representing 25 percent in 1977 and 40 percent in 1978 of the sampled biomass.

## Introduction

Various aspects of the feeding ecology of great blue herons have been studied throughout the United States and Canada (Kirpatrick 1940, Meyerriecks 1960, Dennis 1971, Krebs 1974, Kushlan 1976, Willard 1977, Hoffman 1978, Quinney and Smith 1980, Black and Collopy 1982, and others). In northern Idaho, however, food habits of great blue herons have not been documented. In this region, the species is the most abundant representative of the ardeids and breeding colonies are widely distributed (Larrison 1981).

Collazo (1981) described the breeding biology of great blue herons nesting at Heyburn State Park in Benewah County. This paper documents the food habits of herons at this heronry based on food samples collected during two breeding seasons.

## Methods

Between March and August in 1977 and 1978, regurgitated pellets (castings), boluses, and fish remains were collected at 2-day intervals from the ground beneath nest trees. At weekly intervals, food items were collected from 12 nests that were accessible by climbing. Samples were dated, and stored in plastic bags for later analysis in the laboratory.

Prey items that were collected intact were measured (total length) and weighed (wet weight in grams). Weights of fish that were partially digested, or dry, were determined from a length-weight table (Carlander 1969, 1977).

Air-dried castings were made up almost entirely of normal hair, primarily that of meadow voles. In order to estimate how many voles were in a casting, an average weight of dried skins ($n=20$) was calculated to compare it to the dry weights of castings.

Fish bones, most of which were identified, were collected from the ground. Although these skeletal counts were not included in the frequency of occurrence data presented in this work, they were useful in determining the relative importance of game fish in the diet of herons.

**Results and Discussion**

Brown bullheads and tench represented 15 percent and 12 percent of the sampled prey items for 1977, and 16 percent and 7 percent for 1978, respectively (Table 1). Other species of fish comprised 10 percent in 1977, and 7 percent in 1978, of the total food items collected.

TABLE 1. Frequency of occurrence and biomass (g) of food items collected at a nesting colony of Great Blue Herons, Benewah County, Idaho.

| Prey Species | Year | Frequency/month M | A | M | J | J | % | Biomass X(±)SE | Total Biomass | % |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ictalurus** | 1977 | 4 | 12 | 11 | 38 | 32 | 15 | 170±21 | 16,490 | 30 |
| **nebulosus** | 1978 | 3 | 7 | 43 | 32 | 27 | 16 | 127±21 | 14,224 | 35 |
| **Tinca tinca** | 1977 | 0 | 1 | 4 | 44 | 25 | 12 | 298±26 | 22,052 | 40 |
| | 1978 | 0 | 1 | 6 | 20 | 22 | 7 | 177±31 | 9,027 | 21 |
| **Perca** | 1977 | 0 | 0 | 1 | 18 | 17 | 5 | 36±12 | 1,296 | 2 |
| **flavescens** | 1978 | 0 | 0 | 1 | 12 | 5 | 3 | 29± 6 | 522 | 1 |
| **Lepomis** | 1977 | 0 | 0 | 1 | 17 | 11 | 5 | 57± 5 | 1,653 | 3 |
| **gibbosus** | 1978 | 0 | 0 | 0 | 13 | 11 | 4 | 48± 5 | 1,152 | 3 |
| **Microtus** | 1977 | 82 | 128 | 66 | 81 | 40 | 62 | 35± 3 | 13,895 | 25 |
| **pennsylvanicus** | 1978 | 155 | 123 | 64 | 88 | 35 | 67 | 35± 3 | 16,275 | 40 |
| Other | 1977 | 0 | 2 | 1 | 3 | 4 | 1 | — — | —— | — |
| | 1978 | 0 | 2 | 6 | 10 | 5 | 3 | — — | —— | — |

Estimated numbers of voles occurring per month represented 62 percent in 1977, and 67 percent in 1978, of all food items (Table 1). I assumed that all hair found in castings was that of meadow voles because of the high frequency of bones and skulls of this species. Single skulls of the long-tailed weasel (*Mustela frenata*) and a muskrat (*Ondatra zibethicus*) were also found in castings.

Various other species occurred in low frequencies in the analyses. These amounted to 1 percent in 1977 and 3 percent in 1978 (Table 1). Species in this category and their frequency of occurrence for both seasons were 1 frog (*Rana* spp.), 1 sculpin (*Cottus* spp.), 3 painted turtles (*Chrysemys picta*), 2 northern squawfish (*Ptychocheilus oregonensis*), 10 black crappie (*Pomoxis nigromaculatus*), 1 cutthroat trout (*Salmo clarki*), 1 largemouth bass (*Micropterus salmoides*), 1 northern pocket gopher (*Thomomys talpoides*), 1 crayfish (*Cambarus* spp.), 8 giant water bugs (*Belostomatidae*), and 2 muskrats.

Only small fragments of invertebrates, mainly aquatic arthropods, were recovered. Invertebrates, however, should not be disregarded as an important component in the diet of herons (e.g., Kushlan 1978). Their rarity among these samples may be due to their relatively high digestability (Hibbert-Ware 1940, Kushlan 1978).

Brown bullheads and tench provided the main nutritional needs in this heronry (Table 1). Fish species comprised 75 percent and 60 percent of the total sampled biomass in 1977 and 1978, respectively. The frequency of fish in the samples began to increase in May for both years. This increase coincided with the hatching of young in mid-April and their subsequent demand for food ( Collazo 1981). Also, brown bullheads, tench, yellow perch (*Perca flavescens*), and pumpkinseeds (*Lepomis gibbosus*) become more vulnerable during the nestling period as these fish spawn in May, June, and July in shallow, weedy areas (Simpson and Wallace 1978).

Although fish consumption increased during the breeding season, the frequency of game fish in the samples was low. Of 140 skeletons identified (paired bones), only 1 percent was that of game fish. Thus great blue herons are not believed detrimental to game fish populations at Heyburn State Park and nearby tributaries. In fact, herons probably have a beneficial effect in preying chiefly on what many fishermen and fisheries biologists (Simpson and Wallace 1978) consider nuisance species in Idaho.

Mammals were also an important diet component in this heronry particularly in the early part of the nesting season (Table 1). Mammals, especially voles, are abundant along grassy and moist areas at Heyburn State Park and thus vulnerable to predation (Larrison and Johnson 1981). Early in the season, lakes and nearby tributaries were partially frozen and perhaps mammals were relatively more available to herons than fish.

More information is needed to determine whether food remains beneath nest trees represent the true prey species composition and its relative importance in the diet of great blue herons. This could be investigated by comparing food remains to their prey species preference and seasonality as determined by analyses of boluses and digestive tract contents.

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# The Third Constant

**Abstract**

The history of the "Euler-Mascheroni constant,"

$$\gamma = \lim_{m\to\infty} \left[1 + \frac{1}{2} + \cdots + \frac{1}{m} - \ell n\ m\right] = 0.5772156649\ldots$$

is briefly discussed, with particular attention to the question of how validly Mascheroni's name appears in the term. This discussion is followed by a selection of examples that show how $\gamma$ naturally arises in diverse contexts: coupon collecting, infinite series, the Bessel and gamma functions, differential equations, number theory, and such topics from probability and statistics as moments of the extreme value distributions, the expected value and variance of the sample size of a Jiřina sequential tolerance bound, the coefficient of variation for the Weibull distributions, and the value at the origin of the density of sums of products of uniform variates. These examples give evidence for the claim that e, $\pi$, and $\gamma$ are (except possibly for such simple rational numbers as 0, 1, ½, etc.) the three most important real constants. (Indeed, the three constants are related to one another. It is remarkable, for instance, that $\gamma$ often occurs in association with Euler's formula

$$\frac{\pi^2}{6} = 1 + \frac{1}{2^2} + \cdots + \frac{1}{m^2} + \cdots.)$$

Nevertheless, we remain ignorant today, 250 years after its discovery, of the answers to some deep questions about $\gamma$, such as whether it is transcendental and even whether it is irrational. These mysteries are part of the appeal of the third constant.

## Introduction

Some time ago a candidate for an advanced degree in mathematics was asked, in an oral examination, to name three transcendental numbers. The student named e (the base of the natural logarithms), $\pi$ (the ratio of the circumference of a circle to its diameter), and $\gamma$ (the Euler-Mascheroni constant). No one in the examining committee knew how many were right.

One of the authors of this article, speaking recently before an audience of undergraduates, said, "Let God choose three numbers at random," and wrote down:

3.14159 26535 . . . ,
2.71828 18284 . . . ,
0.57721 56649 . . . .

Immediately someone asked "What is that third number? I recognize the first two, but not the third."

These little stories illustrate two aspects of the mystery of the Euler-Mascheroni constant, given (to ten decimal places) as the third number in the above list. In this

paper, following the *Standard Mathematical Tables* (Beyer 1981), we shall denote this number by $\gamma$ (gamma).

The seminal contributions of Leonhard Euler (1707-83) to science are so extensive that he should need no introduction. But the name of Lorenzo Mascheroni (1750-1800) is scarcely a household word, even in scientific circles, and it is natural to wonder why it should be associated with the great name of Euler in connection with $\gamma$.

**Some History**

Euler apparently discovered the number we are calling $\gamma$ in the 1730's. In a paper called "De progressionibus harmonicis observationes" [Observations on harmonic progressions] (Euler 1911-56, vol. 14, pp. 87-100), first published in 1740 but probably written in 1734-35, he proved that the limit

$$\lim_{n\to\infty} \left(1 + \frac{1}{2} + \cdots + \frac{1}{n} - \ell n\ n\right)$$

exists, called it C, and found its value to six decimal places. A reduced facsimile of the relevant page (*ibid.*, p. 94) is given below to enable the reader to savor Euler's Latin.

11. Quo autem seriei $1+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\cdots+\frac{1}{i}$ summa etiamsi infinita accurate determinetur, singulos terminos sequenti modo exprimo.

Est

$$1 = l2 + \frac{1}{2} - \frac{1}{3} + \frac{1}{4} - \frac{1}{5} + \frac{1}{6} - \frac{1}{7} + \text{etc.}$$

atque

$$\frac{1}{2} = l\frac{3}{2} + \frac{1}{2\cdot 4} - \frac{1}{3\cdot 8} + \frac{1}{4\cdot 16} - \frac{1}{5\cdot 32} + \text{etc.},$$

$$\frac{1}{3} = l\frac{4}{3} + \frac{1}{2\cdot 9} - \frac{1}{3\cdot 27} + \frac{1}{4\cdot 81} - \frac{1}{5\cdot 243} + \text{etc.},$$

$$\frac{1}{4} = l\frac{5}{4} + \frac{1}{2\cdot 16} - \frac{1}{3\cdot 64} + \frac{1}{4\cdot 256} - \frac{1}{5\cdot 1024} + \text{etc.},$$

$$\vdots$$

$$\frac{1}{i} = l\frac{i+1}{i} + \frac{1}{2\cdot i^2} - \frac{1}{3\cdot i^3} + \frac{1}{4\cdot i^4} - \frac{1}{5\cdot i^5} + \text{etc.}$$

His seriebus additis prodibit

$$1 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{i} = l(i+1) + \frac{1}{2}\left(1 + \frac{1}{4} + \frac{1}{9} + \frac{1}{16} + \text{etc.}\right)$$
$$- \frac{1}{3}\left(1 + \frac{1}{8} + \frac{1}{27} + \frac{1}{64} + \text{etc.}\right)$$
$$+ \frac{1}{4}\left(1 + \frac{1}{16} + \frac{1}{81} + \frac{1}{256} + \text{etc.}\right)$$
$$\text{etc.}$$

Quae series cum sint convergentes, si proxime summentur, prodibit

$$1 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{i} = l(i+1) + 0{,}577218.$$

Si summa dicatur $s$, foret, ut supra fecimus,

$$ds = \frac{di}{i+1} \quad \text{ideoque} \quad s = l(i+1) + C.$$

Huius igitur quantitatis constantis $C$ valorem deteximus, quippe est $C = 0{,}577218$.

In another paper, written within a year or two (*ibid.*, pp 108-121), Euler used another method to find his C to sixteen places.

Since Mascheroni was not born until 1750, it would seem that Euler's priority in this matter could hardly be contested because of anything Mascheroni did. But there is more to the story.

In the first volume of Euler's epochal textbook on integral calculus, *Institutiones calculi integralis* (published in 1768 but written years earlier), he divided each term of the Maclaurin series for $e^x$ by x, then integrated termwise to obtain the formula

$$(1) \qquad \int \frac{e^x}{x}\,dx = C + \ell x + \frac{x}{1!} + \frac{1}{2}\frac{x^2}{2!} + \frac{1}{3}\frac{x^3}{3!} + \ldots;$$

here $\ell x$ stands for the natural logarithm of x and C is just a constant of integration. Then he goes on to say: "And putting here $e^x = z$, so that $x = \ell z$, we are able to integrate $\frac{dz}{\ell z}$ by a series:

$$(1') \qquad \int \frac{dz}{\ell z} = C + \ell\ell z + \frac{\ell z}{1} + \frac{1}{2}\frac{(\ell z)^2}{1 \cdot 2} + \frac{1}{3}\frac{(\ell z)^3}{1 \cdot 2 \cdot 3} + \frac{1}{4}\frac{(\ell z)^4}{1 \cdot 2 \cdot 3 \cdot 4} + \text{etc.};$$

for the integral to vanish when $z = 0$, the constant C would be infinite, while in the remaining cases nothing can be concluded" (Euler 1911-56, vol. 11, pp. 127-28). (Here it should be noted that there are certain difficulties, obvious to the modern eye, with Euler's statement. If in fact we set $z = 0$ in the right side of (1'), all terms but the first are undefined; the term $\ell\ell z$ is, so to speak, even doubly undefined. The series makes sense (with real numbers) only for $z > 1$, i.e. $\ell z > 0$, and then it converges very rapidly. In the passage immediately following that quote, Euler shows—somewhat obscurely—that he is aware of this "inconvenience," and concludes by saying: "Therefore the nature of this transcendental function [*i.e.*, that defined by the integral in (1')] is too little known."

Here we may be permitted to digress long enough to point out that if we put $z = -y$ in the integral in (1) and then integrate by parts in a style whose casualness would not have offended Euler, we obtain

$$(2) \qquad \int \frac{e^x}{x}\,dx = \int \frac{e^{-y}}{y}\,dy = (\ell n\ y)e^{-y} + \int (\ell n\ y)e^{-y}\,dy.$$

In modern notation (as in Abramowitz and Stegun 1964, p. 228) Ei denotes the exponential integral defined by

$$(3) \qquad Ei(x) = -\bar{\int}_{-x}^{\infty} \frac{e^{-t}}{t}\,dt = \bar{\int}_{-\infty}^{x} \frac{e^{t}}{t}\,dt \quad \text{for } x > 0$$

(Here the bar through the integral sign means that the principal value is used.) This function has the series representation

$$(4) \qquad Ei(x) = \gamma + \ell n\, x + \sum_{n=1}^{\infty} \frac{x^n}{n(n!)} \quad \text{for } x > 0.$$

Comparison of equations (1), (3), and (4) shows how close Euler was.

(Another exponential integral is defined—for complex arguments—by

$$E_1(z) = \int_z^{\infty} \frac{e^{-t}}{t}\,dt \quad \text{for } |\arg z| < \pi\,,$$

where the path of integration passes through no nonpositive real points in the complex plane (*ibid.*).)

In 1790 Mascheroni published the first of two volumes under the title *Adnotationes ad calculum integralem Euleri*, which are reprinted at the end of Euler 1911-56, volume 12. In the first section of this work, Mascheroni claims to show that if the function represented by $\int \frac{dz}{\ell z}$ vanishes when $z = 0$, then for $0 \leq z < 1$, the formula quoted from Euler, with the term $\ell\ell z$ replaced by $\ell(-\ell z)$, holds if C (which he calls A) is taken to be 0.5772 . . . , i.e. "Euler's constant." Mascheroni gave this number to 32 decimal places, and went on to work out an extensive theory of the function $\int \frac{dz}{\ell z}$, which he called the "hyperlogarithm."

This is what base there is for attaching Mascheroni's name to the constant, and there has naturally been some disagreement about the equity of the practice.

Lorenzo Mascheroni was an interesting character. Born in Lombardy in 1750, he took holy orders at the age of nineteen. His early interest in literary writing, in both Italian and Latin, was increasingly displaced by scientific—especially mathematical—studies. After successive associations with lesser schools, in 1786 he assumed the professional chair for algebra and geometry at the University of Pavia, where he served several terms as rector. In 1797 he dedicated one of his mathematical works to Napoleon, who took an interest in him. This led to his being invited to Paris as a member of the international commission that created the metric system. In 1800 he died in Paris after a short illness.

Mascheroni's best-known poems were concerned with science; in his masterpiece, "Invito a Lesbia Cidonia" (1793), he sought, successfully, to persuade a neighboring countess to visit the scientific museums of Pavia. Mascheroni was himself the subject of an allegorical eulogy, "Mascheroniana" (1801) by a much more important poet,

Vincenzo Monti (1754-1828) (Parini 1951).

C. F. Gauss (1777-1855) discovered that Mascheroni's value for $\gamma$ was wrong from the twentieth decimal place onward. Much later, J. C. Adams computed it to 263 places (Adams 1878). Almost a century after that, Beyer and Waterman found $\gamma$ to more than 7000 places with the help of the Maniac II computer (Beyer and Waterman 1974). It is probable that by now someone who is not necessarily endowed with the great gifts of an Euler or a Gauss or the fortitude of an Adams has machine-computed many additional digits of the decimal representation of $\gamma$.

The interested reader may consult Glaisher (1871) for further details of the early history of Euler's constant.

#### Some Useful Approximations

The constant $\gamma$ is most often thought of as Euler first discovered it, *viz.* in connection with the asymptotic behavior of the partial sums of the series of reciprocals of the positive integers. We shall use the following notation for these partial sums:

$$h_0 = 0, \quad h_m = 1 + \frac{1}{2} + \cdots + \frac{1}{m} \quad \text{for } m = 1, 2, \ldots.$$

Then $\gamma = \lim_{m \to \infty} [h_m - \ln m]$, which may also be expressed by

$$(5) \qquad h_m \cong \gamma + \ln m \quad \text{for large } m.$$

This approximation makes an error of less than 2 percent at $m = 10$ and less than 0.1 percent at $m = 100$; but it is improved if a number, say $a'$, is added before the logarithm is taken, so as to obtain, for large m,

$$(6) \qquad h_m \cong \ln(a' + me^{\gamma}) = \gamma + \ln(m + a),$$

where $a = a' e^{-\gamma}$. When $a'$ is chosen to be 1 (Saunders 1963), the approximation (6) is exact when $m = 0$ and makes errors of about 2 percent, 0.2 percent, and 0.01 percent when $m = 1$, 10, and 100 respectively. If $a = \frac{1}{2}$, then $h_m > \gamma + \ln(m + \frac{1}{2})$ for $m = 0, 1, 2, \ldots$. This has been shown by our colleague Duane DeTemple in a private communication. Although equality does not hold in (6) when $a = \frac{1}{2}$ and $m = 0$ $(\gamma + \ln \frac{1}{2} \cong -0.12)$, he found uniform improvement over the choice $a' = 1$ for $m \geq 1$; e.g. the approximation (6) with $a = \frac{1}{2}$ errs by about 0.014 percent and 0.00113 percent for $m = 10$ and $m = 30$, respectively.

If a is chosen to be $\exp(h_{m_0} - \gamma) - m_0$ for any prescribed non-negative integer $m_0$ (e.g. $a = .50396006\ldots$ if $m_0 = 10$), then the approximation (6) is exact at $m = m_0$.

The approximation (6) can serve a didactic purpose in showing how very slowly the harmonic series diverges. Let $m_A$ be the smallest integer m for which $h_m > A$. It has been shown by using (6) with $a = \frac{1}{2}$ (Boas and Wrench 1971) that

$$m_A = [e^{A-\gamma} + \tfrac{1}{2}].$$

(Here and subsequently [x] denotes the "integral part" of the real number x, *i.e.* the

largest integer that does not exceed x.) Thus $m_5 = 83$; $m_{20} \cong 27{,}240{,}000$; and

$$m_{100} \cong 1.509 \times 10^{43}.$$

In words, although the partial sums of the harmonic series "approach infinity," it would take one with over $10^{43}$ terms to exceed such a modest value as 100.

#### The Coupon-Collecting Problem

We shall now present a few illustrations from various areas of mathematics which show that the Euler-Mascheroni constant is not obscure but in fact arises frequently and often surprisingly. Of course, as a quantity defined as a limit, $\gamma$ arises only in problems that have the requisite "infinite" character.

Suppose, first, that a bag contains m coupons numbered 1 through m. We draw one coupon, replace it, draw again, replace, and so on. As each coupon is drawn, we record its number. Suppose we want to record r different coupons—where, of course, $r \leq m$. We ask: What is the expected number of drawings needed to accomplish this?

$$(7) \qquad m\left(\frac{1}{m} + \frac{1}{m-1} + \cdots + \frac{1}{m-r+1}\right) = m\,(h_m - h_{m-r}).$$

If we wish to record some fraction $p < 1$ of all the different coupons, of which there are m, then by equation (7) the expected number of drawings necessary is

$$m(h_m - h_{m-[pm]}) \cong -m \ln(1-p) \quad \text{for m large.}$$

Thus we see that when m is large the expected number of drawings needed to record half the coupons is not much greater than half, *viz.* $\ln 2 = .693$, while the corresponding multiple of m necessary to record 95 percent of the coupons is $\ln 20 \cong 3$. So it is for any fixed fraction; but if we wish to record *all* the coupons, then the expected number of drawings is simply $mh_m$. Surprisingly enough, now the multiplicative factor not only depends upon m but it grows without bound as m increases!

A similar situation arises if a person does not like red-cherry jelly beans but has r of them mixed in a bag with g green-lime jelly beans. Suppose that this person reaches into the bag once a day and takes a jelly bean at random. If it is green, she eats it; if it is red, she puts it back. What is the expected number of days until she consumes the last green jelly bean? The answer again involves partial sums of the harmonic series and so is amenable to approximations in which $\gamma$ appears: the expected number of days is

$$g + rh_g \cong g + r\,\ln(1 + ge^{\gamma}).$$

#### Some Classical Occurrences

Knopp (1928, p. 271) offers another instance where Euler's constant comes up, but not by way of approximation; If $S_p = \sum_{n=2}^{\infty} n^{-p}$ $(p > 1)$, then $\sum_{p=2}^{\infty} \frac{1}{p} S_p = 1 - \gamma$.

The reader may find this a challenging exercise.

Another item from Knopp (*ibid.*, p. 523) uses Euler's summation formula, which gives an explicit expression for the difference between the sum $\sum_{j=0}^{n} f(j)$ and the cor-

responding integral $\int_0^n f(x)dx$, *viz.*

$$(8) \qquad \sum_{j=0}^{n} f(j) = \int_0^n f(x)dx + \frac{1}{2}(f(0) + f(n)) + \int_0^n P(x)df(x),$$

where

$$P(x) = x - [x] - \frac{1}{2} \quad \text{for } x \geq 0.$$

But notice that P is periodic with period 1; thus for every nonintegral value of x, we have the Fourier series representation

$$(9) \qquad P(x) = -\sum_{n=1}^{\infty} \frac{\sin(2n\pi x)}{n\pi}.$$

In the special case where $f(x) = (x + 1)^{-1}$ and $m = n - 1$, (8) gives (after some changes of variables)

$$h_m = \ln m + \frac{m + 2}{2(m + 1)} - \int_1^m \frac{P(x)}{x^2}\,dx.$$

From this it follows directly that

$$(10) \qquad \lim_{m \to \infty} [h_m - \ln m] = \gamma = \frac{1}{2} - \int_1^{\infty} \frac{P(x)}{x^2}\,dx.$$

which in combination with (9) gives a reasonably fast method for calculating $\gamma$.

Euler's constant is also useful in normalizing Bessel functions. The functions $J_0$ (Bessel's function of the first kind of order 0) and the function $y_2$ defined by

$$y_2(x) = J_0(x)\ln x + \sum_{m=1}^{\infty} h_m x^m$$

form a basis for the solution space of Bessel's differential equation

$$xy'' + y' + xy = 0.$$

For technical reasons, it is convenient to replace $y_2$ by the linear combination $\frac{2}{\pi}(y_2 + (\gamma - \ln 2)J_0)$. This is what is called Bessel's (or Neumann's) function of the second kind of order 0. Its definition involves both $\gamma$ and the partial sums $h_m$.

It should not be surprising now that $\gamma$ appears in standard solutions of the more general Bessel's equation

$$x^2y'' + xy' + (x^2 - p^2)y = 0,$$

where p is a real number. This extremely important differential equation has applications to problems in elasticity, fluid motion, potential theory, diffusion, wave propagation, etc. (Watson 1944).

#### Number Theory

The theory of numbers also provides many examples where $\gamma$ appears in the solution of problems (Dickson 1919). As is to be expected, these problems typically concern asymptotic estimates for number-theoretic functions.

For example, for any positive integer m let $\tau(m)$ be the number of divisors of m, and let $T(m) = \tau(1) + \tau(2) + \ldots + \tau(m)$. In 1849, P. G. L. Dirichlet (1805-59) showed that

$$T(m) = m \ln m + (2\gamma - 1)m + O(\sqrt{m})$$

(*ibid.*, p. 282). Many other formulas of this type have been discovered.

An example of a somewhat different kind was discovered by Ch. J. de la Vallée Poussin (1866-1962[!]) in 1898:

$$\lim_{m\to\infty}\left[\sum_{p\le m}\left(\frac{m}{p} - \left[\frac{m}{p}\right]\right)\right]\Big/\psi(m) = 1 - \gamma.$$

Here p stands for a prime and $\psi(m)$ is the number of primes p satisfying $p \le m$ (*ibid.*, p. 330). Thus if a positive integer m is divided by each of the primes p less than or equal to m, the average of the "fractional parts" of the resulting numbers approaches $1 - \gamma$ as m grows large!

#### Appearances in Statistics

The Euler constant $\gamma$ appears mysteriously in statistics, where it is related to moments of certain probability distributions. One of these is Gumbel's (type I) asymptotic distribution of extreme values. The distribution of maximum values has the double exponential form

$$F(t) = \exp\{-\exp[-\alpha(t - \beta)]\} \text{ for } -\infty < t < +\infty \tag{11}$$

where $\alpha$ and $\beta$ are real ($\alpha > 0$), and are the scale and location parameters, respectively. If a random variable T has the distribution F given by (11), then its mean and variance are given by

$$ET = \beta + (\gamma/\alpha) \text{ and } Var(T) = \pi^2/6\alpha^2.$$

The expectation can be verified by setting $-\ln y = \alpha(t - \beta)$ in the definition to obtain

$$ET = \beta - \frac{1}{\alpha}\int_0^\infty (\ln y)e^{-y}\,dy = \beta + (\gamma/\alpha).$$

This depends on the exact representation

$$\gamma = -\int_0^\infty (\ln y)e^{-y}\,dy, \tag{12}$$

which appears as formula 4.331 in Gradshtyn and Ryzik 1980. (Note that this gives a precise interpretation for the last integral in equation (2).) Formula 4.335 in the same source yields

$$(13) \qquad \int_0^\infty (\ln x)^2 e^{-x}\, dx = \frac{1}{6}\pi^2 + \gamma^2,$$

which is needed in computing the value of the variance.

Analogously, the asymptotic distribution of smallest values has the form

$$G(t) = 1 - \exp\{-\exp[\alpha(t - \beta)]\} \text{ for } -\infty < t < \infty,$$

with mean $\beta - (\gamma/\alpha)$ and variance $\pi^2/6\alpha^2$.

One of Euler's most celebrated discoveries was the sum of reciprocals of the squares of the positive integers:

$$\frac{1}{1^2} + \frac{1}{2^2} + \cdots + \frac{1}{m^2} + \cdots = \frac{\pi^2}{6}.$$

We see that the specters of this series and of the series of the reciprocals of the positive integers themselves haunt these distributions in much the same way that $\pi$ haunts the normal distributions.

The number $\gamma$ also comes up on modern sequential methods in statistics. It occurs, as in the coupon-collecting problem, in the expected size of a sample needed to determine a distribution-free tolerance region from a sequence of observations independently and identically distributed by any continuous distribution, say F. Suppose the procedure is to determine an upper (or, alternatively, a lower) bound which will exceed at least a given fraction $\beta$ of all future observations with a specified confidence. A method proposed by Jiřina (1961) goes as follows: Select a positive integer k, then stop sampling when for the first time the maximum observation has not changed through k subsequent observations. The maximum observation (bound) B so determined will be, as a function of the observations, a random variable. Then $Q = F(B)$ is the fraction of all future observations that will be less than B. This random variable, called the coverage, also depends on the value of k. Saunders (1963) has shown that the distribution of the coverage is

$$P[Q > \beta] = (1 - \beta)\exp\left[\sum_{j=1}^{k} (\beta_j/j)\right] = \exp\left[-\int_0^\beta x^k(1 - x)^{-1}\, dx\right].$$

(The second equality is based on the identity

$$\sum_{j=1}^{k} (t^j/j) = -\ln(1 - t) - \int_0^t x^k(1 - x)^{-1}\, dx \quad \text{for } 0 \leq t < 1$$

and on the fact that the random sample size to determine B has the factorial moment generating function

$$M(\beta) = \int_0^{\beta} t^k \exp\left[\sum_{j=1}^{k} (t_j/j)\right] dt.)$$

Thus the expected sample size to determine B is given by

$$M'(1) = \exp h_k \cong 1 + ke^{\gamma}.$$

Here we have used the approximation (6), which was first derived (Saunders 1963) for just this purpose. Using the same approximation, one finds that the variance of the sample size is approximately $k(2 - e^{\gamma})\ (1 + ke^{\gamma})$. So again we find that $\gamma$ appears in these expectations as it did in those for the coupon-collecting problem.

Another problem in statistics concerns the asymptotic behavior of a coefficient of variation. The coefficient of variation of a random variable is defined as the ratio of its standard deviation to its mean.

The Wiebull distribution is given by

$$F(y) = 1 - \exp\left[-(y/\beta)^{\alpha}\right] \quad \text{for } y, \alpha, \beta > 0.$$

For this distribution the coefficient of variation is independent of $\beta$:

$$\nu_{\alpha} = \left[\Gamma\left(1 + \frac{2}{\alpha}\right) - \Gamma^2\left(1 + \frac{1}{\alpha}\right)\right]^{\frac{1}{2}} / \Gamma\left(1 + \frac{1}{\alpha}\right) .$$

Here $\Gamma(x)$ $(x > 0)$ is the well-known gamma function—also due to Euler. From published values for this function one can find the table

| $\alpha$ | 1 | 2 | 3 | 4 | 10 |
|---|---|---|---|---|---|
| $\nu_{\alpha}$ | 1 | .5227 | .3602 | .2806 | .1203 |

This raises the natural question of the limiting behavior of $\nu_{\alpha}$. Now

$$(\alpha\nu_{\alpha})^2 = \left[\frac{\Gamma\left(1 + \frac{2}{\alpha}\right) - \Gamma^2\left(1 + \frac{1}{\alpha}\right)}{(1/\alpha)^2}\right] \Big/ \Gamma\left(1 + \frac{1}{\alpha}\right) .$$

By L'Hôpital's rule,

$$\lim_{x \to 0} \frac{\Gamma(1 + 2x) - \Gamma^2(1 + x)}{x^2} = \Gamma''(1) - [\Gamma'(1)]^2.$$

Thus

$$\lim_{x \to 0} \alpha\nu_{\alpha} = \{\Gamma''(1) - [\Gamma'(1)]^2\}^{\frac{1}{2}}. \tag{14}$$

To our surprise, we find that the integrals needed to evaluate the expression on the right are precisely those given already in displays (12) and (13). The results are

$$\Gamma'(1) = -\gamma,$$
$$\Gamma''(1) = \frac{1}{6}\pi^2 + \gamma^2.$$

This shows not only that the limit in (14) is $\pi^2/6$, but that the Euler constant is the negative of the slope of the gamma function at 1 and, moreover, that the second derivative at 1 involves both the Euler constant and Euler's value for the sum of the reciprocals of the squared integers.

A final comment for this section: Professor George Marsaglia of the Department of Computer Science at Washington State University has proved that if $U_1, U_2, \ldots$ is a sequence of independent identically distributed uniform random variables on the unit interval, then the variate

$$V = U_1 + U_1U_2 + U_1U_2U_3 + \cdots$$

has a density $f_v$ defined on $[0,\infty)$ which satisfies $f_v(0) = e^{-\gamma}$.

#### The Psi Function

The appearance of the gamma function in the preceding section calls to mind another, closely related manifestation of the Euler constant, namely that in connection with the "digamma function" or, as it is now more often called, the "psi function" $\psi$ defined by

$$\psi(x) = \frac{d}{dx} \ln \Gamma(x).$$

This function is defined for all real values of x for which $\Gamma(x)$ is defined, namely all but the nonpositive integers. It is tabulated in Abramowitz and Stegun (1964).

Simple calculations show that for all x in the domain of $\psi$,

$$\psi(x + 1) - \psi(x) = \frac{1}{x}. \tag{15}$$

Furthermore, from formula $\Gamma'(1) = -\gamma$ and the elementary fact that $\Gamma(1) = 1$, we have

$$\psi(1) = -\gamma. \tag{16}$$

Formulas (15) and (16) together give us a simple formula for the values of $\psi(x)$ when x is a positive integer:

$$\psi(m) = h_{m-1} - \gamma \quad \text{for } m = 1, 2, \ldots .$$

An interesting series formula for $\psi$, which (of course!) involves $\gamma$, is

$$\psi(x) = -\frac{1}{x} - \gamma + \sum_{m=1}^{\infty} \frac{x}{m(x + m)}. \tag{17}$$

Interesting articles could be written about the psi function and its derivatives (the so-called "polygamma functions"); but fortunately for us, this has already been done.

For a start, we refer the curious reader to Ross (1978); a very recent interesting use of the formula (17) is presented in Ross (1983).

### Conclusion

An innumerate friend of one of the authors once remarked, "If mathematicians are so smart, why don't they make $\pi$ come out even?" At least, we do know that $\pi$ (as well as e) is irrational, so it will never "come out even." It perhaps would be even more interesting *not to know* whether these numbers ever will "come out even." This was the condition of humankind until 1770, when Lambert first proved the irrationality of $\pi$. And it is our condition now with respect to the Euler-Mascheroni constant: no one knows whether $\gamma$ "comes out even," much less whether it is transcendental. (That $\pi$ and e are transcendental has been known for over a century.) Thus, although $\gamma$ has been with us for about 250 years, and although we have seen it arise surprisingly often in many disparate situations, we remain as largely ignorant of its deeper properties as Euler was.

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# Influence of Glyphosate Herbicide on Small-Mammal Populations in Western Oregon[2]

**Abstract**

The effect of glyphosate application on vegetation and small mammal populations in the Coast Range of western Oregon was investigated. Diversity, abundance, and biomass of small-mammal populations increased one year post-spray on glyphosate-treated sites as compared to control sites. These changes were ephemeral and the above parameters were similar to pre-spray values two years after glyphosate application. The changes in diversity, abundance, and biomass were primarily a result of the increase in numbers of *Microtus oregoni* following an increase in grass and forb cover on treated grids one year post-spray. The temporary effects of glyphosate treatment on vegetation had no detrimental effects on small mammal populations.

## Introduction

One of the underlying principles of the ecology of small-mammal populations is that most species are limited in their distributions and abundance by the composition and/or structure of vegetation. Small-mammal species often coexist by occupying structurally distinct microhabitats (Rosenzweig and Winakur 1969; Rosenzweig 1973; Dueser and Shugart 1978, 1979; Kitchings and Levy 1981; M'Closky and Fieldwick 1975; Murua and Gonzalez 1982). Consequently, alterations of plant communities may have a noticeable effect on the composition of small-mammal communities.

The application of herbicides to recent clearcuts constitutes one form of alteration to plant communities. Herbicides are used to reduce shrubs and deciduous trees and enhance growth of conifers during the first years after logging. The phenoxy herbicides 2,4-D and 2,4,5-T have been the most commonly used herbicides, but 2,4,5-T has been restricted from use due to trace dioxin contamination. Glyphosate is effective on a variety of deciduous trees and shrubs (Sutton 1978, Newton and Roberts 1979) and is currently a replacement for 2,4,5-T.

Herbicides may have differing effects on small-mammal communities when vegetation is altered significantly. Numbers and foods of pocket gophers (*Thomomys talpoides*) have been reduced following application of 2,4-D (Keith

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*et al.* 1959, Johnson 1964, Tietjen *et al.* 1967) or atrazine (Crouch 1979). When atrazine and 2,4-D were used to control herbaceous vegetation, small-mammal species (i.e., *Microtus* sp.) that prefer grassy habitats were less abundant on treated than untreated plots (Borecco *et al.* 1979). In contrast, Sullivan and Sullivan (1982) found little effect of Roundup on the abundance of small-mammal populations comprised of *Peromyscus maniculatus, Microtus oregoni, Tamias townsendii,* and *Sorex* spp. They (Sullivan and Sullivan 1981) also reported no apparent adverse effects on reproduction, growth, and survival of *Peromyscus maniculatus* one year after the treatment.

Most studies have reported the response of single species to herbicide applications other than glyphosate. This paper reports the effects of glyphosate herbicide on small-mammal communities inhabiting recent clearcut areas in western Oregon.

#### Materials and Methods

*Description of study areas.*—This study was conducted on two recent (less than seven years post-cutting) clearcuts in the Coast Range of western Oregon (Siuslaw National Forest, Alsea Ranger District, Lane and Lincoln Co.). The sites were about 15 km apart, of northern aspect, and 275-375 m in elevation. Both sites were designated by the USDA Forest Service (USFS) as in need of herbicide treatment for brush control. Treatment was postponed on one site (control site, 21 ha) for the duration of this study. The treated site (glyphosate site) was aerially sprayed on 11 and 13 October 1979 at a rate of 1 qt (0.9ℓ) of glyphosate in sufficient water to equal 10 gal (37.9ℓ) of spray per acre (0.4 ha). About 26 ha of this 36 ha site were treated to reduce salmonberry (*Rubus spectabilis*) that was suppressing conifer growth.

Vegetation on the study areas was characterized by a dominance of shrubs, especially salmonberry, thimbleberry (*Rubus parviflorus*), and vine maple (*Acer circinatum*). The low shrub-herb layer was dominated by sword-fern (*Polystichum munitum*), bracken fern (*Pteridium aquilinum*), tansy ragwort (*Senecio jacobaea*), foxglove (*Digitalis purpurea*), pearly everlasting (*anaphalis margaritacea*), Oregon oxalis (*Oxalis oregana*), and several grasses (*Agrostis exarata, Aira caryophyllea, Dactylis glomerata, Festuca arundinacea, Holcus lanatus, Luzula parviflora*). Red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*), with maximum heights <6 m, were sparse and provided the only deciduous overstory.

*Field and laboratory procedures.*—Two trapping grids, at least 100 m apart, were established on each site. Sixty-five Sherman live traps (7.6 x 7.6 x 25.4 cm) were placed on each grid at 15-m intervals and baited with rolled oats and peanut butter. The two grids on a site were trapped simultaneously for nine days, followed immediately by trapping the two grids on the other site for nine days. Trapping was conducted during late-August and early-September of 1979, 1980, and 1981; traps were checked daily beginning at sunrise. Trapped animals were marked by toe-clipping, aged, and released at the trap-site.

The total number of individuals captured was used as an index of abundance for all species, as the number of recaptures for most species was insufficient to estimate populations with capture-recapture methods. Other studies on the same species of cricetid rodents (Gashwiler 1972, Sullivan and Sullivan 1982) found live-trapping to be a reliable method of estimating relative abundance; however,

this approach probably underestimated the abundance of shrews (*Sorex* spp.) as described by Williams and Braun (1983). Relative abundance of species was used to calculate an index of diversity (H') and evenness (J') (Pielou 1975). Biomass of each species was estimated by multiplying average weight of a species by its abundance.

Differences in species abundance and biomass were tested for statistical significance with chi-square ($X^2$) analyses at the 0.05 level. Because diversity and evenness measures were small values and not derived by repetitive sampling, they could not be subjected to tests for significant differences.

#### Results

*Vegetative response*—Detailed analysis of vegetation on the study sites is presented elsewhere (Morrison 1982). Briefly, application of glyphosate partially defoliated over 50 percent of the salmonberry and thimbleberry one year post-spray. However, only about 5 percent of these shrubs were actually killed and completely defoliated by the treatment. By two years post-spray, normal leaves had redeveloped on damaged plants with the shrub layer generally resembling the one before treatment. The application of glyphosate was described as fair to moderately effective by USDA Forest Service personnel (J. Warner, personal communication).

Herbaceous (grass and forb) cover increased on the glyphosate site from pre-spray (40 percent) conditions to one year (45 percent) and two years (62 percent) post-spray (Morrison 1982, Table 12), primarily as a result of an increase in herbaceous cover under damaged shrubs. In contrast, herbaceous cover ($\sim$60 percent) remained relatively constant on the control site for the three years.

*Community measures of small-mammal populations*—Total abundance and biomass of small mammals did not change significantly over the three years as a result of glyphosate spraying. However, total abundance increased ($P < 0.05$) one year post-spray, then declined ($P < 0.05$) two years post-spray on both glyphosate grids (Table 1). Abundance of small mammals increased ($P > 0.05$) each year on one control grid and was relatively stable ($P > 0.05$) on the other grid. Biomass of small mammal communities increased ($P < 0.05$) considerably over the two years on one glyphosate grid while biomass on the other grid increased ($P < 0.05$) one year post-spray and declined ($P < 0.05$) two years post-spray (Table 1). Biomass decreased ($P < 0.05$) on one control grid each successive year and remained relatively stable ($P > 0.05$) on the other grid.

Diversity and evenness of small-mammal communities showed no marked changes after two years following spraying of glyphosate (Table 1). However, diversity increased one year post-spray, then declined two years post-spray on both glyphosate grids and one of the control grids. Diversity on the second control grid remained relatively stable one year post-spray, then declined two years post-spray. Evenness of small-mammal communities increased each successive year on one glyphosate grid; evenness remained stable one year post-spray, then declined two years post-spray on the other grid (Table 1). Evenness increased one year post-spray and decreased two years post-spray on both control grids.

In summary, abundance, biomass, diversity, or evenness did not decline one year post-spray on the glyphosate grids and were comparable to pre-spray values

TABLE 1. Abundance, diversity (H'), evenness (J') and biomass (g) for small-mammal communities on control and glyphosate sites before and after glyphosate treatment.

| Grid No. | Parameter | Pre-spray (1979) | 1 yr. post-spray (1980) | 2 yr. post-spray (1981) |
|---|---|---|---|---|
| | | GLYPHOSATE SITES | | |
| | Abundance[a] | 45 | 71 | 44 |
| | H' | 0.55 | 1.27 | 0.64 |
| 1 | J' | 0.50 | 0.65 | 0.92 |
| | Biomass | 899 | 1215 | 668 |
| | Abundance | 25 | 56 | 43 |
| | H' | 0.87 | 1.51 | 0.93 |
| 2 | J' | 0.79 | 0.78 | 0.52 |
| | Biomass | 818 | 1119 | 1405 |
| | | CONTROL SITES | | |
| | Abundance | 28 | 43 | 54 |
| | H' | 1.21 | 1.32 | 0.81 |
| 1 | J' | 0.68 | 0.74 | 0.42 |
| | Biomass | 1197 | 1172 | 1238 |
| | Abundance | 51 | 44 | 58 |
| | H' | 0.66 | 1.57 | 1.01 |
| 2 | J' | 0.41 | 0.71 | 0.56 |
| | Biomass | 1756 | 1423 | 1156 |

[a]Total number of individuals of each species captured.

and those for the control grids. In fact, the prominent changes in these communities after glyphosate application was an increase in abundance, diversity, and biomass one year post-spray and a return to pre-spray levels two years post-spray. Glyphosate spray had no detrimental effects on small-mammal populations.

*Single species responses.*—Three species (*Peromyscus maniculatus, Tamias townsendii, Microtus oregoni*) were captured in sufficient numbers to discuss the effects of glyphosate on their individual populations (Table 2). *Peromyscus maniculatus* was the most abundant species on all grids during the three years of trapping (Table 2). Numbers of *Peromyscus maniculatus* increased significantly ($P < 0.05$) over the three years on one control and one glyphosate grid and decreased slightly ($P > 0.05$) over the same period on the other glyphosate grid (Figure 1). Thus, populations of *Peromyscus* did not appear to be influenced by the vegetative changes resulting from the spraying of glyphosate.

Numbers of *Microtus oregoni* were greater ($P < 0.05$) on the glyphosate than the control grids during all three years of sampling (Table 2). This greater abundance of *Microtus* was due to a significant ($P < 0.01$) increase in their populations one year post-spray on both glyphosate grids (Figure 2). Populations declined ($P < 0.05$) two years post-spray on these grids. Meanwhile, numbers of *Microtus oregoni* were low and remained relatively stable on both control grids for all years.

*Tamias townsendii* was equally ($P > 0.05$) abundant on the two control and one glyphosate grids but significantly ($P < 0.05$) lower on the second glyphosate grid (Table 2). *Tamias* populations remained stable one year post-spray on the glyphosate grids but declined slightly ($P < 0.05$) on one grid and increased

TABLE 2. Abundance and percent of total capture of small-mammal species caught on control and glyphosate sites during 1979, 1980, and 1981.

| Species | Control sites | | Glyphosate sites | |
|---|---|---|---|---|
| | Grid 1 | Grid 2 | Grid 1 | Grid 2 |
| *Peromyscus maniculatus* | 82(65.6) | 104(68.0) | 100(62.5) | 69(55.6) |
| *Tamias townsendii* | 18(14.4) | 17(11.1) | 6(3.8) | 19(15.4) |
| *Microtus oregoni* | 8(6.4) | 11(7.2) | 44(27.5) | 18(14.5) |
| *Sorex vagrans* | 4(3.2) | 4(2.6) | 3(1.9) | 4(3.2) |
| *S. towbridgii* | 2(0.8) | 1(0.6) | 4(2.5) | 5(4.0) |
| *S. pacificus* | — | 6(3.9) | 2(1.2) | 3(2.4) |
| *Zapus trinotatus* | 8(6.4) | 5(3.3) | 1(0.6) | 4(3.3) |
| 3 other species[b] | 3(2.4) | 4(2.6) | — | 2(1.6) |
| Total | 125 | 152 | 160 | 124 |

[a]Values = number of different individuals caught (% of total).

[b]*Microtus longicaudus, Neotoma cinerea, Mustela erminea.*

slightly ($P < 0.05$) on the other grid two years post-spray (Figure 3). Numbers of *Tamias* on both control grids remained relatively constant over the three years (Figure 3).

#### Discussion

The principle change in abundance, diversity, evenness, and biomass of small-mammal communities following glyphosate treatment was an increase in numbers of *Microtus oregoni*. This increase was apparently related to increased herbaceous cover one year post-spray following defoliation of the shrub layer. The decline in numbers of *Microtus oregoni* two years after treatment may have been related to the recovery of shrubs. These results and interpretations are consistent with Gashwiler (1972) who found higher numbers of *Microtus oregoni* in clearcut areas than in virgin forest, and population increases of the species on clearcut areas up to four years after burning. *Microtus* spp. use habitats characterized by a predominance of grasses and forbs (Goertz 1964). Neither *Peromyscus maniculatus* nor *Tamias townsendii* were significantly affected by glyphosate application. The above results are applicable to glyphosate applications that are fair to moderately efficient; more effective applications may have quite different effects.

Sullivan and Sullivan (1982) studied the response of small-mammal populations to application of Roundup herbicide to a 20-year-old conifer plantation and found little difference in population changes of deer mice, Oregon voles, and chipmunks between the control and experimental areas. Their results for Oregon voles are in contrast to the results of our study and may be due to the more advanced successional development of their 20-year-old stand as compared to our 7-year-old clearcut. They (Sullivan and Sullivan 1981) also observed no adverse effects of Roundup herbicide on reproduction, growth, or survival of deer mice/year after treatment.

Black and Hooven (1974) and Borrecco *et al.* (1979) reported on the responses of small mammal communities to herbicide-induced vegetation changes (primarily

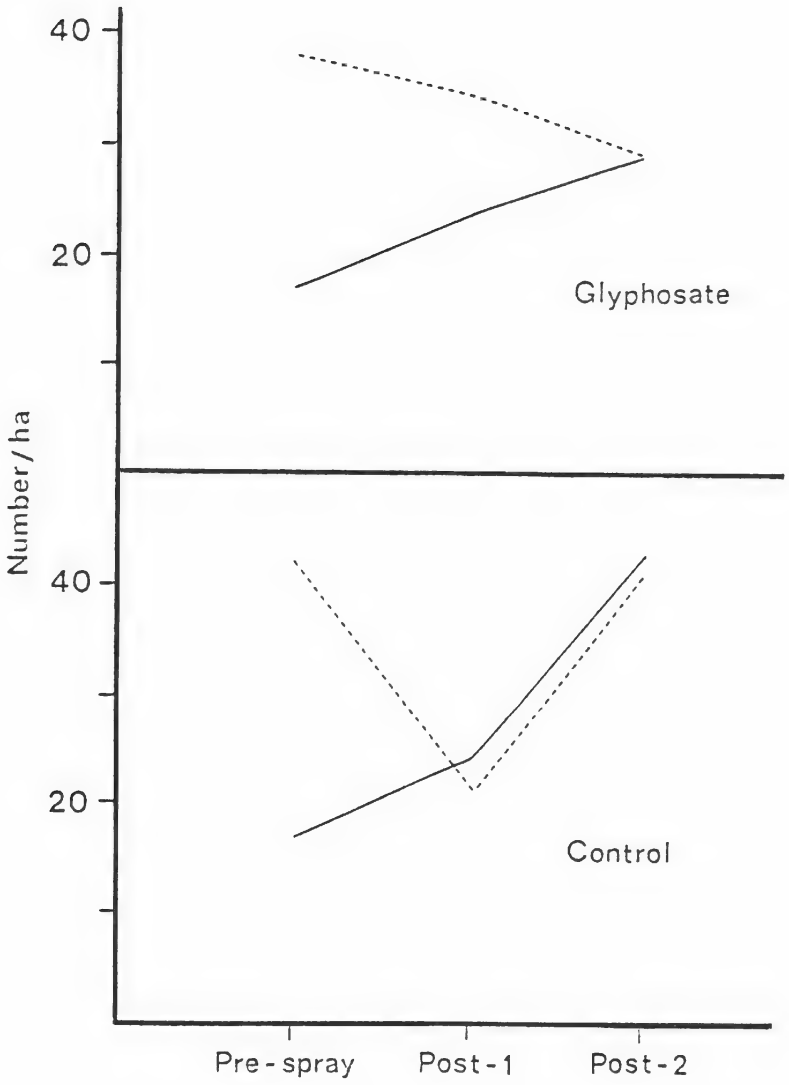


Figure 1. Density (number/ha) of *Peromyscus maniculatus* captured on grids 1 (dashed line) and 2 (solid line) on the control and glyphosate sites before (Pre-spray) and 1 (Post-1) and 2 (Post-2) years after treatment with glyphosate.

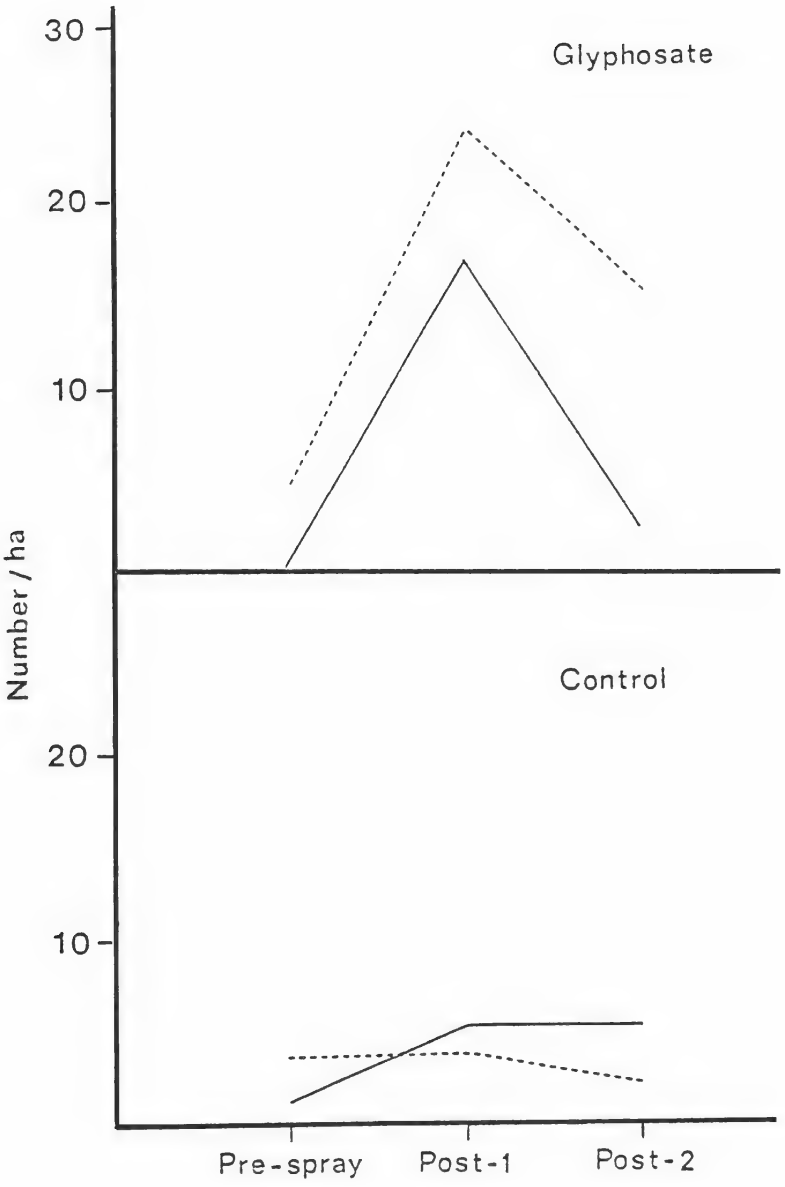


Figure 2. Density (number/ha) of *Microtus oregoni* captured on grids 1 (dashed line) and 2 (solid line) on the control and glyphosate sites before (Pre-spray) and 1 (Post-1) and 2 (Post-2) years after treatment with glyphosate.

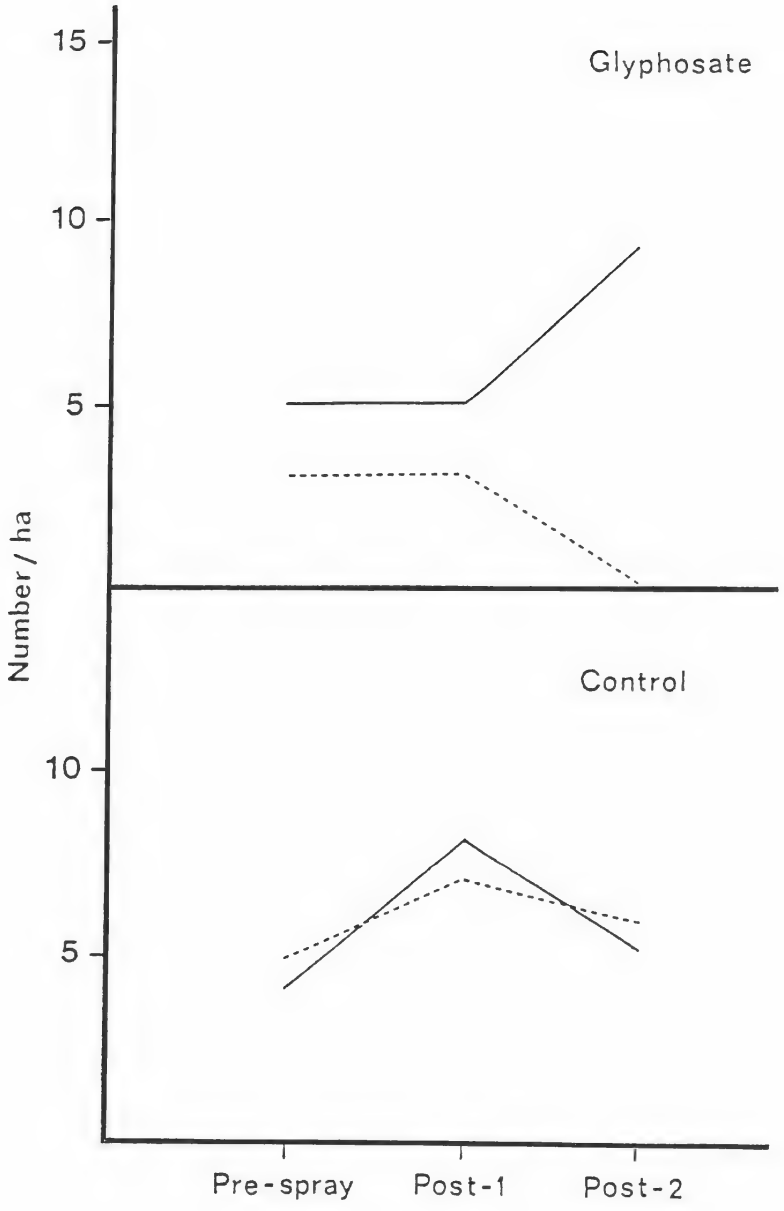


Figure 3. Density (number/ha) of *Tamias townsendii* captured on grids 1 (dashed line) and 2 (solid line) on the control and glyphosate sites before (Pre-spray) and 1 (Post-1) and 2 (Post-2) years after treatment with glyphosate. Note that scale used in this figure differs from that used in Figures 1 and 2.

2,4-D and atrazine) on clearcuts in western Oregon. Herbicides were applied in their studies to reduce grasses and forbs, a different prescription from that on our treated sites. A substantial decrease in numbers of *Microtus oregoni, Zapus trinotatus,* and *Sorex vagrans* was noted following reduction of grassy habitats by herbicides (Black and Hooven 1974, Borrecco *et al.* 1979). Small mammal populations returned to near pre-spray numbers by two years after treatment, which was attributed to the concomitant regrowth of grass (Black and Hooven 1974).

Our results and those of Black and Hooven (1974) and Borrecco *et al.* (1979) indicate that changes in small mammal communities occur following herbicide modification of vegetation on early-growth clearcuts in western Oregon. Such changes are most noticeable with species that use grassy habitats (particularly microtine rodents), and numbers of such species increase or decrease depending on the purpose and type of treatment. Given rapid regrowth of vegetation damaged by herbicides, small mammal communities rapidly return to pre-treatment numbers often within a two-year period.

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# Shoot Production and Mineral Nutrient Assimilation in Cheatgrass Communities

## Abstract

Shoot production at peak yields in cheatgrass communities on the U.S. Department of Energy's Hanford Site in southeastern Washington during the 1968-69 growing season averaged 212 and 370 g per $m^2$ dry wt. in communities located at 520 m (high) and 323 m (low) elevations respectively. Litter (dead plants) at the high elevation averaged 362 g per $m^2$ as compared to 225 g at the low elevation. More precipitation and more soil water were present at the high elevation. Shoots and litter from the high elevation had lesser concentrations of assimilated nitrogen suggesting that the availability of nitrogen from the root zone was a factor constraining shoot production at the high elevation.

## Introduction

Cheatgrass (*Bromus tectorum* L.) is an annual grass of Eurasian origin that has formed self-sustaining communities on man-disturbed lands throughout the semi-arid, relatively cold wet winter, and hot dry summer, climate of eastern Washington (Daubenmire 1970, Mack 1981). Although cheatgrass has been studied from an autecological point of view (Hulburt 1955, Harris 1967, Hinds 1975) and as an undesirable rangeland grass (Young *et al.* 1979); it has received relatively little study as a functional, self-sustaining plant community (Cline and Rickard 1973, Uresk *et al.* 1979, Rickard and Sauer 1982).

The purpose of this study was to determine annual shoot production in two 30-year old cheatgrass communities at different elevations and to compare their concentrations of shoot assimilated mineral nutrients.

## Study Area

The study area is the Arid Lands Ecology (ALE) site a 300 $km^2$ ecological research study area located on the U.S. Department of Energy's Hanford Site in eastern Washington. Dryland wheat was raised at several places on the ALE Site prior to government acquisition but farming ceased in 1943 when the land was acquired for government use. After abandonment the fields were promptly invaded by cheatgrass. After 30 years there has been only a token invasion of the fields by the native perennial taxa although the fields are surrounded by vast acreages of native sagebrush-bunchgrass communities (*Artemisia tridentata-Agropyron spicatum*) (Rickard and Sauer 1982). The land of the ALE Site had a history of livestock grazing prior to 1943, but since that time livestock grazing has been essentially excluded, with only fugitive grazing until 1968 when all livestock grazing was excluded.

#### Methods

Communities at elevations of 520 and 323 meters above mean sea level were chosen for this study. Single study plots each 20x50 m (0.1 ha) in size were located near the center of each field. Samples of surface soil from five locations within each of the study plots were taken to a depth of one decimeter using a soil auger. Soil samples were air dried, screened through a 2 mm mesh screen to remove roots and other organic debris, and thoroughly mixed before being submitted to chemical analyses. The soil type at both sites is Ritzville silt loam (Daubenmire 1970).

Six to ten one square foot (0.093 $m^2$) quadrats were sampled for shoot biomass at each field. These quadrats were randomly located within each study plot at harvest dates distributed from the beginning to the end of the spring growth period March to May in 1969. Live shoots were severed at ground level and hand-segregated into two general botanical categories; cheatgrass and forbs. On the date of peak harvest in May, the ripe spikes of cheatgrass (culms with attached caryopses), were cut from the attendant foliage (straw) so that mineral analyses could be conducted on the separate tissues. Dead standing and prostrate plant materials (litter) were cleared from those quadrats harvested at the beginning and at the end of the spring growing season. All plant materials were oven dried at 50-55°C and weighed. The results are expressed as grams dry weight per $m^2$. Dried shoots and litter were milled to pass a 2 mm screen and aliquots taken for chemical analyses of nitrogen, phosphorous, potassium, and calcium.

The nitrogen concentrations of plant and soil samples were determined by the Kjeldahl method, P was determined by colorimetry, and Ca and K by atomic absorption spectrometry (A.O.A.C. 1965).

Precipitation was measured at each field using standard U.S. Weather Bureau rain gauges. Soil water was determined by taking duplicate soil cores at one decimeter depth increments to one meter deep by sampling periodically from the beginning to the end of the spring plant growth season. Water content of soil samples was determined gravimetrically after oven-drying at 105°C. Plant available soil water was judged to be the soil water content in excess of 6 percent on a dry weight basis.

#### Results and Discussion

On the average, soil organic matter, nitrogen, phosphorus, potassium, calcium, pH, and total bases were greater on the low elevation field than on the high elevation field (Table 1). The growing season precipitation (October 1968-May 1969) was 3.4 cm greater on the high elevation field, 25.1 cm as compared to 21.7 cm. At the end of the spring growing season the available soil water had been mostly extracted from the soil profile by the evapotranspiration process at the low elevation field (Figure 1). A small amount of available soil water remained in the soil profile at the high elevation community at the end of the spring growing season indicating that cheatgrass was not so efficient at extracting the soil water that had penetrated deeper than 0.5 meters.

At the high elevation community, cheatgrass dominated shoot biomass from beginning to end of the spring growing season. Lance-leaf microseris (*Microseris lanciniata*), a perennial, and yellow salsify (*Tragopogon dubius*), a biennial, were

TABLE 1. Soil properties, means and ranges of values, (n = 5), obtained for samples of the surface dm of soil from high and low elevation cheatgrass communities in southeastern Washington.

| Soil Properties | High Elevation | Low Elevation |
|---|---|---|
| Organic Matter % | 1.6 (1.5-1.8) | 2.0 (1.6-3.5) |
| Nitrogen % | .073 (.064-.086) | .094 (.072-.112) |
| Phosphorus μg/g | 34 (32-38) | 32 (24-46) |
| Potassium μg/g | 1100 (940-1210) | 1400 (1080-1630) |
| Calcium μg/g | 2600 (2500-2900) | 3200 (2900-3700) |
| Soil pH | (6.4-6.9) | (7.0-7.3) |
| Bases meq/100g | 10.6 (10-11.4) | 12.5 (11.6-13.6) |

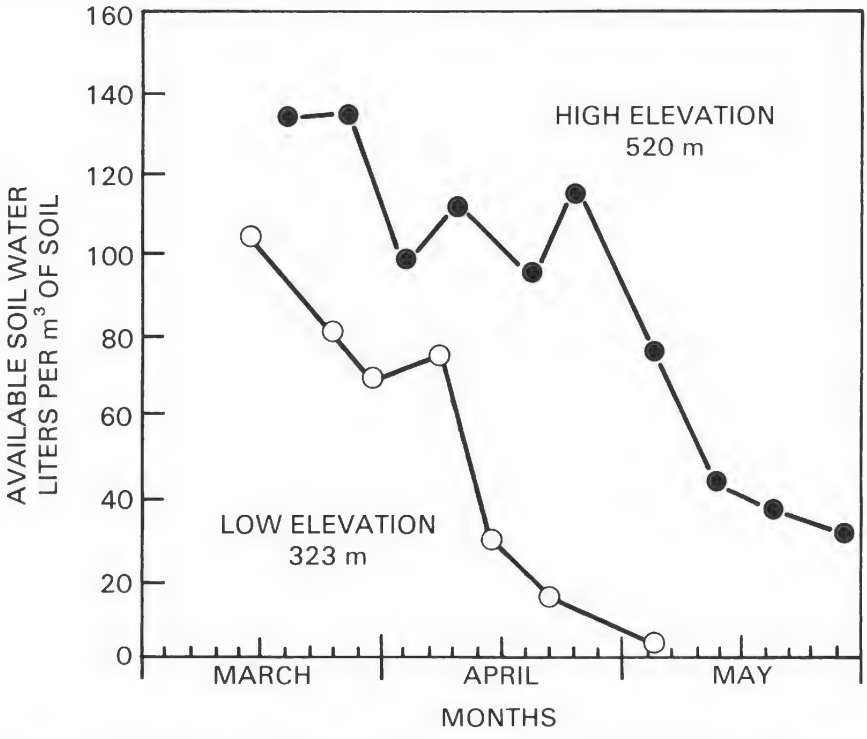


Figure 1. Decline of available soil water in the upper meter of soil during the spring growing season at high and low elevation cheatgrass communities on the Arid Lands Ecology (ALE) Site in southeastern Washington.

the most abundant forbs in this community. The low elevation community supported about equal amounts of cheatgrass and an annual forb, tumble mustard (*Sisymbrium altissimum*). Microseris and yellow salsify did not grow at the low elevation. Shoot biomass attained its peak in late May at 212g per m² dry weight on the high elevation field and at 370 g/m² in early May on the low elevation field (Figure 2). At peak shoot production litter weights average 362 and 225g per m² on the high and low elevation fields, respectively. Using t-test statistics, the difference between mean shoot biomass at peak yield at the two elevations was

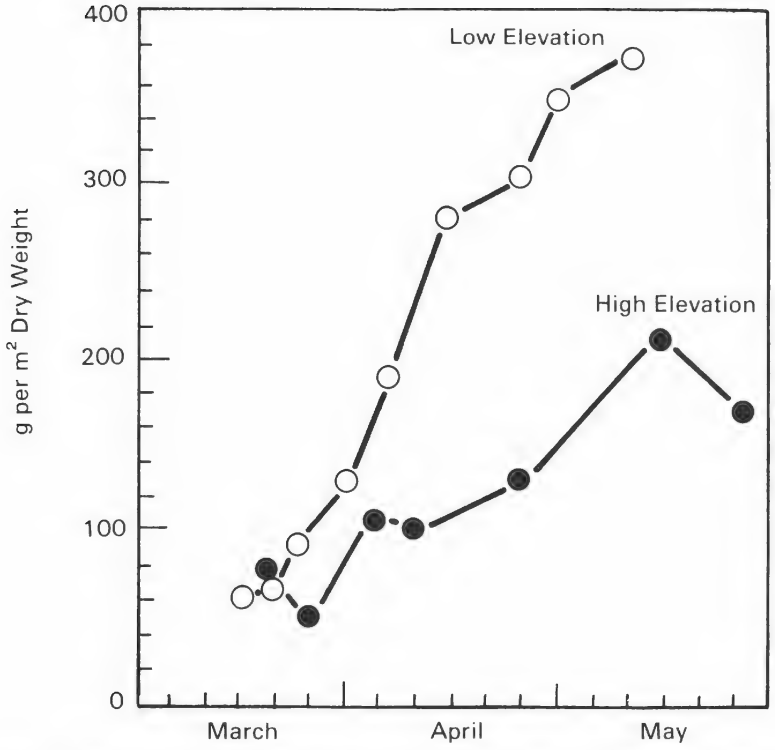


Figure 2. Increases in shoot biomass during the spring growing season in cheatgrass communities at high and low elevations on the Arid Lands Ecology (ALE) Site in southeastern Washington.

significant at $P < .001$ level. Mean litter biomass was statistically significant at the $P < .01$ level (Steel and Torrie 1980). The low elevation cheatgrass community produced more shoot biomass than the high elevation community even though the plants were rooted on a soil profile that contained less available water (Figure 1). Air temperatures and precipitation regimens of the two fields are only slightly different. Over a 10 year period, precipitation on the high elevation field has averaged about 15 percent greater during the October-May growing season, 22.5 cm as compared to 19.5 cm (Thorp and Hinds 1977). Minimum air temperatures in January at the high elevation averaged $-17.5$ and $-15.5°C$ at the high and low elevations, respectively. The close similarities in microclimate at the two sites suggests that edaphic factors rather than atmospheric factors are the constraints to shoot production at the high elevation field. The role of microclimate and soil as a determinant of cheatgrass growth and nitrogen assimilation are intimately related and cannot be separated in most kinds of field investigations (Hinds 1975).

As the growing season progressed concentrations of N, P, K, and Ca in cheatgrass shoots declined. Nitrogen, P, and K concentrations also tended to decline in forb shoots but Ca concentrations tended to increase (Figure 3). In both communities, forb shoots had higher concentrations of N, P, K, and Ca than did cheatgrass shoots (Figure 3).

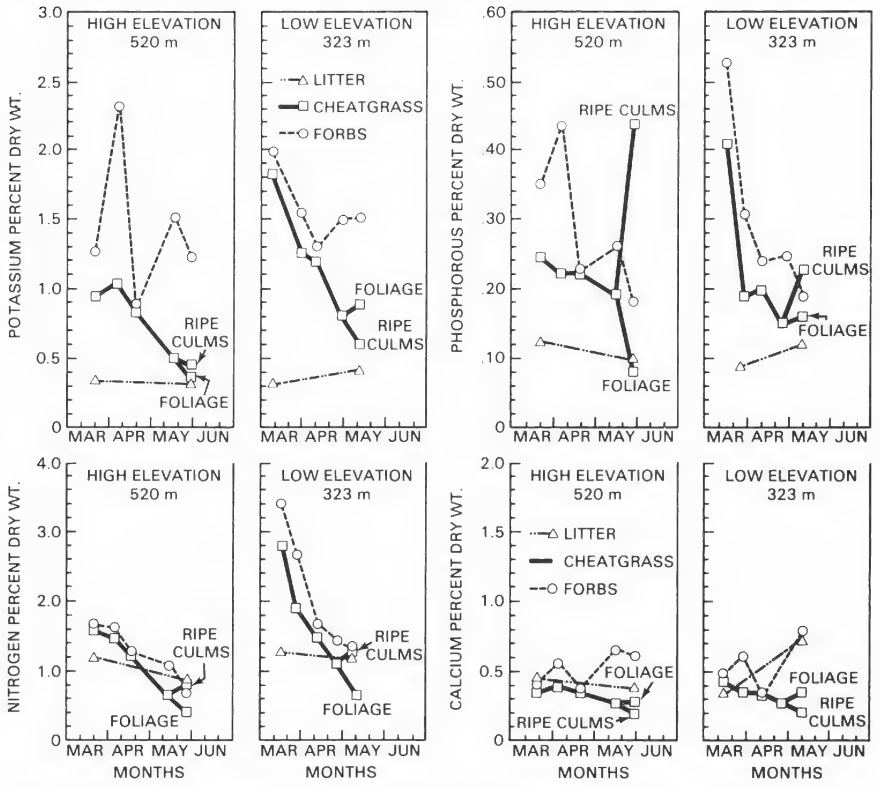


Figure 3. Nitrogen, phosphorus, potassium, and calcium concentrations in shoots of cheatgrass and forbs and litter from high and low elevation cheatgrass communities on the ALE Site in southeastern Washington during the spring growing season.

The ripened culms of cheatgrass had greater concentrations of N and P than their attendant foliage but foliage had greater concentrations of Ca (Table 2). Potassium had its greatest concentrations in foliage rather than ripened culms at the low elevation but at the high elevation the ripened culms had the greater concentrations of K.

The litter had lower concentrations of K and P and higher concentrations of N and Ca than did the mature shoots. This suggests that P and K are not so strongly retained in the dead plants (litter) and that N and Ca are more strongly retained in the litter. Calcium concentrations of litter probably show elevated levels of Ca because the calcium bound in dead plants is not as readily mobilized by leaching and by the decay processes as P and K. The elevated concentrations of N in litter could be due to assimilation of nitrogen by microorganisms utilizing the organic carbon in the litter as an energy source. Also there may be some differential inputs of N to the litter from wet and dry depositions from the atmosphere at the two locations.

The plant soil ratio (concentration in dry plant tissue/concentration in dry soil) is one way to express the ability of plants to obtain mineral nutrients from their

TABLE 2. Mean concentrations (percentages of dry weight ± SE) of N, P, K, and Ca in cheatgrass foliage, ripe culms, forb shoots, and litter from high and low elevation cheatgrass communities.

| Elevation | Cheatgrass | Culms | Forbs | Litter |
|---|---|---|---|---|
| | | Nitrogen | | |
| High | 0.38 ± .01 | 0.82 ± .08 | 0.70 ± .03 | 0.78 ± .09 |
| Low | 0.65 ± .08 | 1.38 ± .09 | 1.36 ± .08 | 1.22 ± .05 |
| | | Phosphorus | | |
| High | 0.08 | 0.44 ± .02 | 0.18 ± .009 | 0.10 ± .004 |
| Low | 0.16 ± .03 | 0.23 ± .01 | 0.19 ± .01 | 0.12 ± .03 |
| | | Potassium | | |
| High | 0.35 ± .01 | 0.44 ± .02 | 1.20 ± .13 | 0.32 ± .005 |
| Low | 0.88 ± .14 | 0.57 ± .03 | 1.50 ± .09 | 0.42 ± .04 |
| | | Calcium | | |
| High | 0.29 ± .01 | 0.20 ± .01 | 0.66 ± .04 | 0.39 ± .01 |
| Low | 0.37 ± .05 | 0.21 ± .01 | 0.80 ± .03 | .077 ± .02 |

rooting substrates. The highest plant/soil ratios were obtained for P with lesser values for N>K>Ca (Table 3). Plant/soil ratios for P in forbs from the high and low fields were 53 and 59 respectively, 23 and 50 for cheatgrass foliage, and 29 and 37 for litter. This suggests that plants growing at the low elevation had a greater capacity to obtain P from their rooting substrates than did the plants at the high elevation. The plant/soil ratios for phosphorus were greatest for cheatgrass

TABLE 3. Plant/soil ratios for N, P, K, and Ca in cheatgrass foliage, ripe culms, forb shoots and litter from high and low elevation cheatgrass communities.

| Elevation | Cheatgrass | Culms | Forbs | Litter |
|---|---|---|---|---|
| | | Nitrogen | | |
| High | 5.2 | 11 | 9.6 | 11 |
| Low | 6.9 | 15 | 14 | 13 |
| | | Phosphorus | | |
| High | 23 | 129 | 53 | 29 |
| Low | 50 | 72 | 59 | 37 |
| | | Potassium | | |
| High | 3.2 | 4.0 | 11 | 2.9 |
| Low | 6.3 | 4.1 | 11 | 3.0 |
| | | Calcium | | |
| High | 1.1 | 0.77 | 2.5 | 1.5 |
| Low | 1.2 | 0.66 | 2.5 | 2.4 |

Plant/soil ratio = the concentration of mineral nutrient in dry soil divided by the concentration of the mineral nutrient in dry plant tissue.

ripened culms. This suggests that cheatgrass shoots have some ability to concentrate P in the ripened culms rather than foliage and that this concentration process was most pronounced at the high rather than the low elevation.

The plant/soil ratios for nitrogen in the three categories (cheatgrass foliage, cheatgrass ripened culms, and litter) ranged between 5.2 and 11 on the high field and between 6.9 and 15 on the low field. The ratios for potassium ranged between 2.9 and 11 in the high field and 3-11 on the low field (Table 3). The calcium ratios ranged between 0.77 and 2.5 on the high field and 0.66-2.5 on the low field. These ratios indicate that potassium and calcium were about equally available for shoot assimilation on both fields. Nevertheless, there was a small but consistent difference in plant/soil ratios for N with the low elevation field being more efficient for nitrogen assimilation as judged by the higher plant/soil ratio.

Once mineral nutrients are assimilated into living shoots of cheatgrass they can be reallocated within the plant. In the early stages of cheatgrass growth, mineral nutrients are allocated solely to vegetative tissues. As the growing season advances nutrients are reallocated from foliar tissues to the flowering culms and especially to the developing seeds. The nitrogen and phosphorus incorporated into seeds has the potential to be passed directly to the new generation of seedlings. Although the amount of nitrogen and phosphorus is very small in terms of a single seed, the amount is more impressive when the total seed production is considered as a community component (Figure 4). Approximately 30 percent of the shoot biomass of mature cheatgrass is allocated to ripened culms with 70 percent in the foliage. Not all of the N and P assimilated in seeds is passed on to the new generation of cheatgrass. Some of the seeds do not germinate and they contribute their mineral nutrient burdens to the litter. Also some of the seedlings die and become incorporated into the new litter component (Figure 4). In this way the litter serves as an accumulation site for nutrients as the new litter ages to become old litter, (i.e., more than one year old dead plants). Over a period of time, other nutrients bound in the old litter are transferred to the underlying mineral soil by the breakdown and decomposition of litter and by leaching. Once these nutrients enter the soil they may be available for prompt assimilation by the living plants (Jones and Woodmansee 1979, Woodmansee and Duncan 1980). Cheatgrass communities do not have a capability to store nutrients in long-lived tissues e.g. wood or grass crowns as do sagebrush-bunchgrass communities and other kinds of perennial grass and graminoid communities in western North America. To sustain a high level of shoot production from year to year cheatgrass communities depend upon a prompt return to the root zone of the pool of nutrients bound in dead plants. Coleman *et al.* (1983) have shown that relatively small pools of rapidly cycling components account for the major proportion of the N and P taken up by plants.

The dead tissues of annual grasses are expected to decay more quickly than the woody tissues but the rate of decomposition is not known. This suggests that radioactive isotopes of nitrogen could be used as tracers to determine the transfer rates of shoot nitrogen between the various components of cheatgrass communities as illustrated in Figure 4. The radioactive isotope $^{15}N$ has been used to elucidate the rate of nitrogen transfer in Alaskan forest communities (Van Cleve and White 1980) and the method seems applicable to cheatgrass communities.

The distribution of nitrogen and phosphorus among the major aboveground components of cheatgrass commmunities in Washington can be compared with

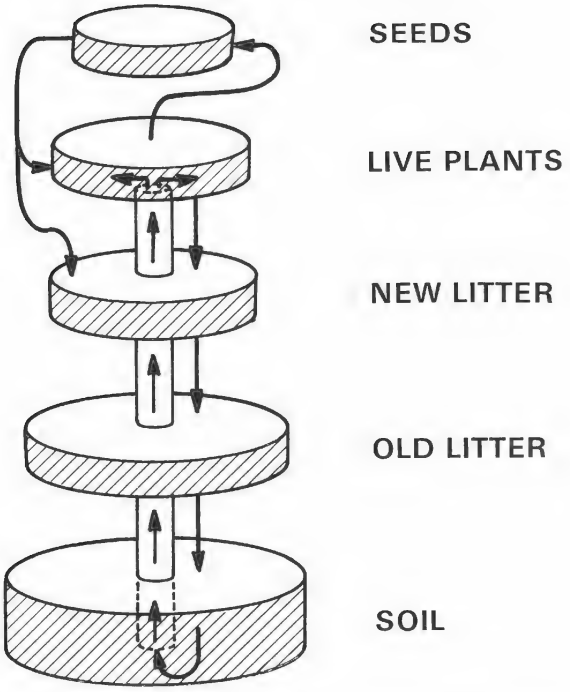


Figure 4. Schematic diagram showing the major community components of a cheatgrass community and the expected routes of mineral nutrient movement.

other kinds of low production wild plant communities in western North America (Chapin 1980, Woodmansee and Duncan 1980). Twenty-four percent of the total nitrogen in the aboveground biomass was in the litter component of a California annual grass community (Table 4). This compares with values of 20 and 67 percent for the cheatgrass communities in this study. The litter component of cheatgrass communities contained 24 and 53 percent of the aboveground P as compared to 19 and 27 percent in a California annual grass community. These data indicate that spatial and temporal heterogeneity is to be expected in annual grass communities and that several consecutive years of study are required to obtain representative values.

The aboveground biomass of cheatgrass communities contained 1.56-2.6 percent of the total community N and 8 percent of the P (Table 5). In contrast, Arctic wet meadow and tussock communities contained less than one percent of the community N and only 0.3-1.3 percent of the P. The relatively large percentage of aboveground P in the cheatgrass communities is attributed to the high allocation of P to the ripened culms of cheatgrass as compared to low P content foliar tissues.

A shortgrass prairie (*Bouteloua gracilis*) community in eastern Colorado had about the same amount of N in the total biomass as did the cheatgrass communities (Table 5) but the prairie community had a greater percentage of N allocated to aboveground biomass. This is a reflection of the large amount of living biomass

TABLE 4. Comparison of N and P in shoot biomass and litter (g per m²) in annual grass communities in Washington and California. ( ) = percent of total biomass.

| Category | Location | | | |
|---|---|---|---|---|
| | Washington High Elev. | Washington Low Elev. | California[1] | California[1] |
| | | Nitrogen | | |
| Grass | 1.26 (30) | 2.76 (43) | 1.29 (16) | 3.60 (63) |
| Forb | 0.13 (3) | 2.31 (37) | 4.71 (60) | 0.72 (13) |
| Total Shoot | 1.39 (33) | 5.07 (80) | 6.00 (76) | 4.32 (75) |
| Litter | 2.82 (67) | 1.30 (20) | 1.92 (24) | 1.40 (24) |
| Total | 4.21 | 6.37 | 7.92 | 5.72 |
| | | Phosphorus | | |
| Grass | 0.29 (43) | 0.46 (41) | 0.36 (29) | 0.25 (40) |
| Forb | 0.03 (4) | 0.39 (35) | 0.65 (52) | 0.20 (32) |
| Total Shoot | 0.32 (47) | 0.85 (76) | 1.01 (81) | 0.45 (72) |
| Litter | 0.36 (53) | 0.27 (24) | 0.24 (19) | 0.17 (28) |
| Total | 0.68 | 1.12 | 1.25 | 0.62 |

[1]Data from Woodmansee and Duncan (1980). These values are from the same plots in two different years.

TABLE 5. Nitrogen and P (g per m²) in aboveground biomass and the upper 2 decimeters of soil in cheatgrass, shortgrass prairie and wet meadow and tussock meadow communities in western North America and the percent of community N and P in aboveground biomass.

| Community | Location | g N/m² | % | g P/m² | % |
|---|---|---|---|---|---|
| Cheatgrass | WA | 195 | 1.5 | 10.8 | 8.9 |
| Cheatgrass | WA | 250 | 2.6 | 10.0 | 8.0 |
| Shortgrass[1] | CO | 273 | 3.2 | -- | -- |
| Wet Meadow[1] | AK | 960 | 0.9 | 63.2 | 1.3 |
| Tussock Meadow[1] | AK | 964 | 0.9 | 48.7 | 0.3 |

[1]Data from Chapin (1980)

allocated to the crowns of the perennial grasses that characteristically dominate the prairie community.

Most of the self-maintained (climax) plant communities in North America are dominated by long-lived perennial plants e.g. conifer forest communities (*Pinus, Abies, Tsuga, Picea,* and others); deciduous forest communities (*Quercus, Carya, Acer, Tilia* and others); perennial grass and graminoid communities (*Bouteloua, Andropogon, Eriophorum, Carex* and others) and desert communities (*Artemisia, Larrea* and others). The cheatgrass communities in Washington and the annual grass communities in California are exceptions to the general rule of community dominance by perennial plants.

The rather limited geographic extent of annual grass communities in North America is a subject of ecological inquiry. It has been postulated that three general survival strategies have evolved in annual plants—*competitive plants, stress tolerant plants* and *ruderal plants* (Grime 1977). In eastern Washington, cheatgrass grows on the steepest south-facing slopes the plant habitats with the most extreme microclimates (Sauer and Rickard 1979, Hinds 1975, Rickard and Warren 1981). This indicates that cheatgrass is a stress tolerant taxon. Cheatgrass is regarded by dryland wheat farmers as a noxious weed because it competes with fall planted winter wheat for soil water and for scarce mineral nutrients. In this respect cheatgrass is a ruderal taxon favored by repetitive soil disturbance by plowing. Rangelands, especially those that have experienced years of overgrazing by livestock to the point where the native grasses and forbs have been weakened or killed, are readily invaded by cheatgrass (Daubenmire 1970). Once cheatgrass becomes established on these overgrazed lands it persists for decades and interferes with the reinvasion by the native perennial plants even when native taxa seed sources are close at hand (Daubenmire 1975, Rickard and Sauer 1982). From this point of view cheatgrass is a competitive taxon. The success of cheatgrass throughout the shrubsteppe region of Washington over the past 100 years or so is attributable to its inherent genetic capacity to be stress tolerant, competitive, and ruderal depending on the history of the particular site.

The exploitation of the available soil water and mineral nutrients by annual plants hampers reinvasion by the native perennial grasses and shrubs at least in the short term, 100 years or so. Perhaps over longer periods of time, native plants will eventually be able to invade well-established annual grass communities and even replace cheatgrass as the dominant taxon. Long-lived, large statured, drought-tolerant perennial taxa that have root systems that can penetrate below the relatively shallow rooting depth of cheatgrass would appear to be the most likely perennial plants to be successful at invading cheatgrass communities (Cline and Rickard 1973).

It seems possible that cheatgrass dominated communities may become even more important in the shrubsteppe region in future years than they are today. The isolated remnant stands of once vast acreages of contiguous native shrubsteppe communities will likely become further modified and even replaced by a variety of man-induced ground disturbances and land management practices aimed at growing crop plants and providing forage for livestock through the planting and maintenance of alien perennial grasses. In this way the once extensive gene pool of native shrubsteppe is depleted and the once contiguous populations become isolated islands. The demise of native species would in the long-term seem to favor the expansion of cheatgrass populations.

#### Conclusions

Shoot production of annual grass communities is determined in part by the amount of available water in the root zone and the availability of nitrogen and other nutrients. A cheatgrass community at a low elevation site produced more shoot biomass with a higher nitrogen content than a cheatgrass community at a higher elevation. The low elevation community produced more shoot biomass even though it received less precipitation and had less soil water in the root zone at the beginning of the spring growing season. The higher nitrogen concentrations

in cheatgrass shoots grown at the low elevation site suggests that nitrogen is more biologically available at this site than it is at the higher elevation. The data also suggests that available nitrogen rather than available soil water is limiting shoot production at the higher elevation.

The success of the alien, cheatgrass in the shrubsteppe region of Washington is attributed to its ability to be stress tolerant, competitive, and ruderal depending on the disturbance history of the particular site.

**Acknowledgments**

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# Effects of Decreased Effluents from Nuclear Fuel Reprocessing on $^{137}Cs$ Concentrations in Wildlife

## Abstract

During 1975, additional fiberglass prefilters and HEPA filters were added to the existing air filtering system for atmospheric effluents from the Idaho Chemical Processing Plant (ICPP) on the Idaho National Engineering Laboratory. Pronghorn (*Antilocapra americana*) muscle and liver samples collected near the ICPP prior to filter installation contained Cesium-137 concentrations that were 13 and 18 times, respectively, the concentrations in tissues of control animals. Muscle and liver samples collected after filter installation had only 2.5 times the $^{137}Cs$ concentrations in control tissues. The potential committed dose equivalent to man consuming the muscle and liver of a pronghorn from the ICPP vicinity was reduced by a factor of 10 by the addition of the filtering system. Although not statistically significant ($P > 0.05$), $^{137}Cs$ concentrations in mourning doves (*Zenaida macroura*) were reduced by a factor of four after the additional effluent filters at ICPP were installed.

## Introduction

The Idaho National Engineering Laboratory (INEL) in southeastern Idaho contains important wildlife habitat. Several species occupying this habitat are popular game animals in Idaho. Up to 6000 of the estimated 20,000 to 23,000 pronghorn (*Antilocapra americana*) in Idaho are on the INEL during winters (Reynolds and Rose 1978). Some pronghorn from as far away as Montana also winter on the INEL (Hoskinson and Tester 1980). Additionally, some pronghorn are present on the INEL throughout the year. Thousands of sage grouse (*Centrocercus urophasianus*) also winter on the INEL (Connelly and Markham 1983). Many of these birds remain on the INEL and breed on the various leks or strutting grounds and subsequently raise their young near the various nuclear facilities. Mourning doves (*Zenaida macroura*) are also numerous during the summer and early fall (Trost *et al.* 1976).

The Idaho Chemical Processing Plant (ICPP) on the INEL reprocesses spent nuclear fuel for the recovery of uranium. During this processing and the solidification of the resultant liquid, trace amounts of radionuclides are released with the atmospheric effluents. As a result of these effluents, tissues of various wildlife species such as mourning doves (Markham and Halford 1982), sage grouse (Connelly and Markham 1983), pronghorn (Markham *et al.* 1979, Markham *et al.* 1980, Markham *et al.* 1982), and raptors (Craig *et al.* 1979) in the vicinity of the ICPP contain higher radionuclide concentrations than do tissues from animals residing off the INEL. Several of these species are hunted adjacent to the INEL and are consumed by sportsmen.

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In 1975 additional fiberglass prefilters and HEPA filters were added to the existing air filtering system at the ICPP to more effectively capture radionuclide particulates discharged with the atmospheric effluents (Nelson 1976). The purposes of this paper are to present the effects of this additional filtering of atmospheric effluents on the radionuclide concentrations in edible tissues of game animals in the ICPP vicinity and to estimate the subsequent potential radiation dose to man consuming tissues of wildlife.

#### Materials and Methods

During September 1972 through December 1976, muscle and liver samples were collected from pronghorn antelope occurring within 10 km of the ICPP and from offsite control animals (Markham *et al.* 1982). Mourning dove muscle samples were collected near ICPP and offsite control areas during the summers of 1974-1977 (Markham and Halford 1982). Control animals were generally collected in the mountain valleys northwest of the INEL, which are not in the predominate northeast-southwest wind patterns. Tissues were analyzed for gamma-emitting radionuclides with a 65-$cm^3$ germanium-lithium detector and a computer-controlled multichannel analyzer system. All data were log-transformed before statistical analyses in order to use normal distribution statistics. Dose calculation methods have been previously described (Markham and Halford 1982, Markham *et al.* 1982).

During August 1975 an improved filtration system for atmospheric effluents was installed at the ICPP. A separate filtration system previously existed for filtering gases from the nitrogen oxide containing vessel, the nuclear fuel dissolver, and the waste calcining facility which solidifies the resultant liquid after the nuclear fuel is dissolved and the uranium removed. However, all ventilation air from process cells was discharged directly into the atmospheric effluent stack. The new system provided continuous filtration of ventilation air and increased filtration of gasses previously being filtered. Information concerning size, location and other details of the filtering system has been published (Nelson 1976).

#### Results and Discussion

Although pronghorn muscle and liver tissues occasionally contained Cesium-134, Cobalt-60 and Zirconium-95, and mourning dove muscles occasionally contained $^{134}Cs$, $^{60}Co$ and Chromium-51, the only radionuclide that was consistently detected in both species was $^{137}Cs$ (Markham and Halford 1982, Markham *et al.* 1982). Cesium-137 was detectable in all but one of the muscle and liver tissues of pronghorn collected from both the ICPP and control areas (N = 73). The minimum detectable concentrations in pronghorn muscle and liver was 0.01 pCi/g (pCi = picocurie = $3.7 \times 10^{-2}$ disintegrations/second). Seventy-eight percent of the mourning doves (N = 20) collected near the ICPP contained detectable concentrations of $^{137}Cs$ in muscle tissues. Minimum detectable concentration for $^{137}Cs$ in the dove tissues were 0.4 pCi/g in 1974-1975 and 0.6 pCi/g in 1976-1977. However, only 17 percent of the offsite muscle samples (N = 24) contained detectable $^{137}Cs$.

For the period prior to installation of filters, $^{137}Cs$ concentrations in both muscle and liver tissues from pronghorn collected near the ICPP were significantly ($P < 0.001$) higher than concentrations in similar tissues collected offsite (Table 1).

TABLE 1. Cesium-137 in edible tissues of pronghorn antelope and mourning doves before and after installation of additional atmospheric effluent filters at the Idaho Chemical Processing Plant (ICPP).

| Date | ICPP | | | Control Area | | |
|---|---|---|---|---|---|---|
| | Sample Size | $\bar{X} \pm SD$ | Range | Sample Size | $\bar{X} \pm SD$ | Range |
| | | | Pronghorn Muscle (pCi/g) | | | |
| 1972-Aug. 1975 | 14 | 0.57 ± 0.48 | 0.03 – 1.52 | 12 | 0.04 ± 0.02 | 0.02 – 0.09 |
| Sept. 1975-1976 | 8 | 0.05 ± 0.04 | 0.05 – 0.14 | 5 | 0.02 ± 0.01 | 0.01 – 0.03 |
| | | | Pronghorn Liver (pCi/g) | | | |
| 1972-Aug. 1975 | 12 | 1.04 ± 0.83 | 0.06 ± 1.77 | 10 | 0.06 ± 0.04 | 0.02 – 0.14 |
| Sept. 1975-1976 | 7 | 0.07 ± 0.08 | BDC[a] – 0.20 | 5 | 0.03 ± 0.01 | 0.02 – 0.04 |
| | | | Mourning Dove Muscle (pCi/g) | | | |
| 1974 | 16 | 3.2 ± 3.6 | BDC – 11.6 | 16 | < 0.4 ± 0.1 | BDC – 0.8 |
| 1976 | 4 | 2.0 ± 2.2 | 0.7 – 5.3 | 8 | BDC | BDC |

[a]BDC—Below detectable concentration

After August 1975, $^{137}Cs$ concentrations in pronghorn muscle tissues from the ICPP remained significantly ($P < 0.02$) higher than concentrations from offsite samples. Although the $^{137}Cs$ average concentration in pronghorn liver samples from ICPP during the 1975-1976 sampling period was 2.5 times the average concentration in offsite samples, the difference was not significant ($P > 0.05$).

Cesium-137 concentrations in muscle and liver samples from ICPP pronghorn in the 1972-1975 period were significantly ($P > 0.001$) higher than similar samples collected during the 1975-1976 period. Concentrations in muscle and liver samples from the control area during 1972-1975 were a factor of two higher and were significantly different ($P < 0.05$) from the control samples collected in 1975-1976. Prior to the addition of the new effluent air filtering system, the $^{137}Cs$ average concentrations in muscle and liver samples were 13 and 18 times, respectively, the average concentrations in tissues of control animals. After the addition of the filters, the $^{137}Cs$ average concentrations in pronghorn muscle and liver from the ICPP were only about 2.5 times that in control animals.

Concentrations in mourning dove muscle tissues collected both before and after the addition of the new filter system were significantly higher ($P < 0.001$) than control tissues. Although the $^{137}Cs$ concentrations in the 1974 dove tissues collected near ICPP were almost four times higher than the 1976 ICPP samples, the difference was not significant ($P > 0.05$). Control data for both periods were generally below minimum detectable concentrations.

The total annual $^{137}Cs$ emitted into the atmosphere from the ICPP was considerably reduced by the addition of the new air filtering system (Table 2). Subsequent to this study, annual atmospheric releases of $^{137}Cs$ from the ICPP for the period 1977-1982 ranged from 0.2 to 0.008 Ci (U.S. Department of Energy 1983).

Big sagebrush (*Artemisia tridentata*) is an important food item for pronghorn on the INEL (Johnson 1979). The primary route of entry of $^{137}Cs$ into pronghorn is by ingestion (Markham *et al.* 1982). The biological half-life of Cesium on big sagebrush is approximately 15 days (Millard *et al.* 1983) and the biological

TABLE 2. Annual $^{137}Cs$ atmospheric releases from the Idaho Chemical Processing Plant.

| Year | $^{137}Cs$ Released (Ci) |
|---|---|
| Before Additional Filters | |
| 1972 | 4.6 |
| 1973 | 5.4 |
| 1974 | 6.7 |
| After Additional Filters | |
| 1975 | 0.6 |
| 1976 | 0.1 |

half-life for pronghorn is probably similar to the 2-week half-life in other ruminants (Goldman *et al.* 1965, Hokanson and Whicker 1969). Therefore, $^{137}Cs$ on the forage and in the tissues of pronghorn probably decreased rapidly when the $^{137}Cs$ activity in atmospheric effluents was reduced.

Although $^{137}Cs$ concentrations in surface soil likely did not decrease because of its relatively long physical half-life and slow rate of removal, less than 20 percent of the $^{137}Cs$ intake by pronghorn was from soil ingestion (W. J. Arthur, unpublished data). The amount of $^{137}Cs$ incorporated into the body tissues from this source compared to other sources of consumption is unknown.

If a person consumed the entire muscle mass from a mourning dove equivalent to our sample having the highest concentration of $^{137}Cs$, the potential wholebody committed dose equivalent from the $^{137}Cs$ would be 0.02 mrem. Because of the much larger mass of the pronghorn, potential dose equivalents from a person eating the muscle and liver of a pronghorn would be higher. The dose equivalent to man consuming the combined muscle and liver from one pronghorn having the maximum and average concentration of $^{137}Cs$ would have been 2.7 and 1.0 mrem, respectively, for the periods prior to the addition of the new filters at ICPP and 0.2 and 0.1 mrem, respectively, for the period after the addition of the filters. The maximum and average committed dose equivalent to man consuming muscle and liver from the control areas during these period prior to filter addition were 0.16 and 0.07 mrem, respectively, and 0.05 and 0.03, mrem, respectively, for the period beginning in September 1975.

The reduction in the $^{137}Cs$ concentration in the control pronghorn tissues and the resultant lowering of the potential committed dose equivalent to man is due to decreasing $^{137}Cs$ in worldwide fallout. Although there was a small and statistically significant ($P < 0.05$) dose equivalent reduction related to eating a pronghorn from the control areas during the two periods, the much larger reduction in the dose equivalent from eating pronghorn from the ICPP area likely resulted from the additional filter system installed at the ICPP. The radiation doses to both man and pronghorn were well below the doses of 132-134 mrem per year that these organisms receive from natural sources (Markham *et al.* 1982).

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# Dichotomous Key to Conifer Foliage in the Pacific Northwest

**Abstract**

Plant macrofossils offer an important means for reconstructing past forest composition in the Pacific Northwest. Conifer foliage preserved in sediments can be identified to species using characters visible under a dissecting microscope. A dichotomous key is presented that describes these characters used in the identification of fossil conifer foliage from trees in western Washington.

## Introduction

The forests in much of western Washington, Oregon, and British Coumbia are presently dominated by conifers (Franklin and Dyrness 1973). Numerous studies have traced the history of these forests since the retreat of Pleistocene glaciers (Hansen 1947; Huesser 1973, 1977; Mathewes and Rouse 1975; Tsukada *et al.* 1981; Leopold *et al.* 1982). Most of this work has relied on fossil pollen preserved in lowland lake and bog sediments to reconstruct changes in forest composition within a radiocarbon-dated time framework.

One difficulty with this approach has been the inability to identify certain pollen types to species. *Picea, Abies, Pinus,* and Cupressaceae are several taxa where different species cannot be distinguished on the basis of pollen. Specific identifications of pollen made by some authors have been considered unreliable following more thorough analyses (Mack 1971). Therefore, recent work increasingly relies on macrofossil remains of plants preserved in association with the pollen to distinguish species (Wasylikowa 1979, Birks and Birks 1980). This technique has revealed some unexpected past species occurrences, such as the presence of *Picea engelmannii* Parry and *Abies lasiocarpa* Hook. (Nutt.) in the Puget Lowland during the late Pleistocene (Barnosky 1981).

My recent studies on Mt. Rainier have suggested that past forest composition can be reconstructed using macrofossil assemblages of conifer foliage (Dunwiddie 1983). It was found that coriaceous conifer leaves are frequently well-preserved in sediments from small ponds at most elevations. Furthermore, since macrofossils are usually identifiable to species, past floristic changes could be detected even when, for example, several species of *Abies* grew together.

In this paper, I present a dichotomous key to the macroscopic features of conifer foliage that is frequently preserved in ponds in western British Columbia, Washington, and northern Oregon.

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### Identification of Conifer Foliage

Excellent keys exist for identification of conifers in the Pacific Northwest, based on characters evident on living material or on herbarium specimens (Hitchcock and Cronquist 1973). However, these keys are often unsuitable for distinguishing fossil needles, since critical choices in the key may rely on characters unavailable to the paleobotanist—cone shape, size, leaf arrangement on the branch, bark color, etc. Even when key characters describe foliage, they may be of little use with fossil material. Frequently, macrofossils are broken or fragmented and important features—the shape of the leaf apex or base, for example—may be missing. In quantitative studies, such as the Mt. Rainier work described above, it is critical that all needles and fragments are identified, and not merely the occasional intact one.

A second body of literature relevant to macrofossil identification includes anatomical studies of leaf structure. An excellent bibliography of this work, much of which is in older and less well-known publications, is presented by Delcourt *et al.* (1979). These studies emphasize microscopic cellular features that are evident in thin sections cut with a microtome from modern specimens. One limitation of this approach with macrofossil material is that poor preservation, at times, makes resolution of critical fine cellular features difficult or impossible. A second drawback is the considerable time and effort involved in properly mounting and sectioning material for study with a compound light microscope. This becomes prohibitive in studies where hundreds of needles are examined.

These painstaking microscopic procedures were found to be unnecessary to identify accurately the species of most conifer foliage recovered from pond sediments in the North Cascades. The dichotomous key presented below uses macroscopic features visible with a dissecting microscope at magnifications of 7X to 40X. It was prepared from observations made on fresh and dried foliage collected in western Washington, in conjunction with several anatomical studies (Coulter and Rose 1886, Durrell 1916, Fulling 1934, Harlow 1947, Liu 1971).

Revisions of the key were made on the basis of features noted from examination of hundreds of macrofossil needles in the Mt. Rainier studies (Dunwiddie 1983). Careful study of macrofossils revealed that several features could be seen in preserved needles that normally are not visible in unsectioned fresh material. Some important features are the presence, size, and position of resin canals. These are frequently visible through the epidermis, which is often translucent in fossil needles. Identification of species of *Abies, Tsuga, Pseudotsuga,* and *Pinus* all rely on these features. Thus the emphasis of the key is on features visible in fossil needles, although it can be used on fresh material as well.

As with other vegetative keys, this key at times deviates from a strict sequence that separates species according to families, genera, and then species. This is because when certain features are missing in fossil material, the resemblance between species in different genera may be stronger than between congeneric species. The key has been constructed so that many species may be identified through different leads. This ensures that a proper identification can be made, even when an apex or base may be missing from a needle.

### Dichotomous Key to Conifer Foliage

1a Leaves scale-like, less than 5mm long; single or more often several-many pairs oppositely attached. —Cupressaceae

1b Leaves needle-like, entire needles rarely less than 5mm long; single (may be fascicled in *Pinus*). —Pinaceae

Cupressaceae

Most foliage remains attached to small branches. In sediments, individual leaves may break off, but usually some fragments remain with several leaves attached. Leaf arrangement on these multiple-leaved fragments is a useful character in distinguishing the two tree genera.

1a Multiple-leaved fragments distinctly flattened on all but the smallest branches; apex of dorsi-ventral leaves often obtuse, abruptly narrowing to apiculate tip; lateral leaves rounded on back, tapering gradually to apex; tips of lateral and dorsi-ventral leaf pairs close to same level. —*Thuja plicata* Donn.

1b Multiple-leaved fragments rounded, 4-angled, or only somewhat flattened (smallest branches may be indistinguishable from *Thuja*); dorsi-ventral and lateral leaves similar, gradually narrowing to acute apex, often keeled on back; tips of lateral and dorsi-ventral leaf pairs at different levels (may be sub-equal on smallest branches). —*Chamaecyparis nootkatensis* (D. Don) Spach

Pinaceae

1a Needles triangular or semi-circular in cross-section, with sharp edges; tips tapering to sharp point; bases not greatly differentiated from needle body; needles sometimes attached to woody shortshoot, forming fascicles of 2, 3, or 5; needles parallel-sided, linear, often breaking cleanly into short segments; intact needles rarely preserved. —*Pinus* (p. 189)

1b Needles variously flattened or 3- or 4-sided, often with a medial groove on adaxial surface, if triangular in cross-section, with rounded edges; tips notched, rounded, or acute; bases petiolate or apetiolate, often with conspicuous oval or circular attachment scar; needles always single, parallel-sided and linear only in *Larix*. —2a

2a Needles delicate and linear (less than 1mm thick), sometimes with a short, hooked petiole; tips acute to obtuse; needles flattened, but usually with a prominent to obscure ridge on the ab- and adaxial sides; 2 stomatal rows may be apparent on either side of the midrib on both ab- and adaxial surfaces; usually preserved relatively intact (contrast with *Pinus*).—*Larix* (p. 189)

2b Needles generally robust, neither slender nor linear; other characters various, but not combined as in *Larix* (p. 189) —3a

3a Needles sharply acute, without a medial groove on the adaxial surface; often relatively straight and pungent; base abruptly truncated at point of attachment, or only slightly tapered. —*Picea* (p. 190)

3b Needles blunt, notched, or acute (if derived from cone-bearing branches); medial groove more or less evident on adaxial surface; always more or less dorsi-ventrally flattened; base twisted or straight, but not truncated. —4a

4a Resin canals 1, central near abaxial surface; needles narrowed to a slender petiole; tip obtusely rounded but not notched (if characters not apparent, go to 4b). —*Tsuga* (p. 190)

4b Resin canals 2, laterally arranged on opposite sides of central vascular bundle; petiole little-constricted, or slender in *Pseudotsuga*; tip obtuse, acute, or notched. —*Abies* and *Pseudotsuga*

*Abies, Pseudotsuga,* and *Tsuga*

1a Needle tips notched; point of attachment round and broad (if tip absent, go to 1b, p. 188) —2a

2a Stomata present on ab- and adaxial surface; resin canals remote from lateral margins; petiole little-constricted, often not twisted. —3a

3a Needles frequently C-shaped, curving adaxially; resin canals large, medially located between ab- and adaxial epidermises, but usually not evident near needle base; adaxial stomata in 10-13 irregular rows forming a broad band 1/2 to 2/3 the width of needle surface, often absent near base, but present very close to tip; medial adaxial groove prominent; abaxial stomata in 4-8 rows forming bands on either side of prominent midrib; abaxial margins and midrib free of stomata, and often equal in width to stomatal bands; abaxial epidermis usually concave between midrib and margin. —*Abies lasiocarpa* (Hook.) Nutt.

3b Needles S- or hockystick-shaped; resin canals small, near abaxial epidermis, about midway between midrib and margin; adaxial stomata in 2 distinct bands on either side of shallow medial groove, merging to form a single band near tip; abaxial stomata in 4 bands of 3-5 rows each, separated by midrib and resin canals; stomate-free margins relatively narrow; abaxial epidermis nearly flat between midrib and margin, hence needle cross-section more or less triangular.*Abies procera* Rehder

2b Stomata present only on abaxial surface (occasionally a few on adaxial tip); resin canals small, close to abaxial epidermis and lateral margins; base usually twisted, sometimes hooked or straight.

—*Abies amabilis* (Dougl.) Forbes and *Abies grandis* (Dougl.) Forbes (Needles of these 2 species are difficult to distinguish. Liu (1971) reports that the hypodermis is more conspicuous and well-developed in *A. amabilis* than in *A. grandis*, but microtome cross-sections would be necessary to examine this feature.)

1b Needle tips obtuse, acute, or absent; point of attachment round or elliptical.—4a

4a Stomata present on ab- and adaxial surface —5a

5a Needles more or less straight, not C- or S-shaped; petiole slender; point of attachment small and elliptical.

—*Tsuga mertensiana* (p. 190)

5b Needles C- or S-shaped; petiole broad; point of attachment round and broad (needles with acute tips from fertile branches of *Abies lasiocarpa* and *A. procera* may key out here

—see leads 3a and 3b, p. 188)

4b Stomata present only on abaxial surface. —6a

6a Needles with slender petiole; point of attachment elliptical, longer than broad; tip rounded, not notched. —7a

7a Needle length:width ratio less than 10; needle abruptly contracted into petiole. —*Tsuga heterophylla* (p. 190)

7b Needle length:width ratio greater than 10; needle gradually tapering into petiole.
—*Pseudotsuga menziesii* (Mirbel) Franco
(These 2 species are normally readily distinguished by the number of resin canals—lead 4a, p. 188).

6b Needles with broader petiole; point of attachment nearly round; tip various. —*Abies amabilis, A. Grandis,* and *Pseudotsuga menziesii* (See lead 2b, p. 188 regarding these *Abies* species. *Pseudotsuga* is normally distinguished by its slender petiolate base and rounded, unnotched tip. *Abies* tips are usually notched, or occasionally acutely pointed on needles from fertile branches. If both tip and base are absent, distinguishing these taxa is difficult, although *Pseudotsuga* needles tend to be slenderer than these *Abies* species. Durrell (1916) reports that *Pseudotsuga* has 1 vascular bundle, whereas *Abies* has 2. This feature would require microtome sectioning to see.)

Pinus

Entire needles are rarely found in sediment. Occasionally the lower portions of the fascicles are recovered still attached to woody shortshoots, or the shortshoots alone may be found. Attachment scars are preserved on these shortshoots, such that 2, 3, and 5-needle species can be readily distinguished from each other.

1a Needles semi-circular in cross-section, adaxial surface sometimes concave; convex abaxial surface with 9-10 (15) distinct, evenly spaced rows of stomata across entire surface; stomata regularly spaced within each row as well; adaxial stomata (rarely absent) in 6-8 (11) similar distinct rows; resin canals 2, medial, usually not apparent through epidermis; minute marginal serrations may be present entire length of needle. —*Pinus contorta* Dougl.

1b Needles 3-angled in cross-section; abaxial stomata present or absent. —2a

2a Abaxial surface broadly convex, much longer than either adaxial surface; other features similar to *P. contorta*, although presence of adaxial ridge forming 2 adaxial surfaces, and overall larger size, are diagnostic.
—*Pinus ponderosa* Dougl.

2b Abaxial surface not much longer than either adaxial surface, needles appearing nearly equiangular in cross-section; resin canals nearer to abaxial epidermis, hence often visible in unsectioned material. —3a

3a Stomata usually present only on adaxial surface; when rarely present on abaxial surface, then only near tip; margins minutely serrate up to 1/2 length of needle. —*Pinus monticola* Dougl.

3b Stomata present on both abaxial and adaxial surfaces; 1 to several rows of stomata present along most of abaxial surface; margins minutely serrate only near tip. —*Pinus albicaulis* Engelm.

*Larix*

Distinguishing *L. occidentalis* Nutt. from *L. lyallii* Parl. is difficult based on needle morphology alone. Carlson and Blake (1969) report 8 epithelial cells surrounding

resin canals in *L. occidentalis*, 5 in *L. lyallii*. This feature would require microtome sectioning to see.

*Picea*

1a Needles more or less flattened; adaxial surface planar or slightly ridged, with numerous rows of stomata; abaxial surface with prominent midrib, without stomata, or with only 1 or 2 rows on either side of the midrib; resin canals absent. —*Picea sitchensis* (Bong.) Carr.

1b Needles nearly equally 4-angled; stomata abundant in 4 grooves between angled edges of needles; 1 or 2 large resin canals usually present (needles usually must be sectioned to see resin canals). —*Picea engelmannii* Parry

*Tsuga*

1a Needles strongly flattened; stomata only on abaxial surface; adaxial surface usually with a conspicuous medial groove; petiole very slender and abruptly twisted; tip obtuse. —*Tsuga heterophylla* (Raf.) Sarg.

1b Needles usually only somewhat flattened; stomata on both ab- and adaxial surfaces; medial groove present or inconspicuous; petiole often more gradually tapered, less slender, and not as abruptly twisted as 1a; tip often more acute. —*Tsuga mertensiana* (Bong.) Carr.

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# Archaeological Evidence of Elk in the Columbia Basin

**Abstract**

Traditionally, elk have been considered absent from the Columbia Basin of eastern Washington during post-glacial time. However, elk have frequently been identified in faunal remains associated with Columbia Basin archaeological sites representing early human cultures in this area. Elk remains have been associated with mostly steppe faunas, suggesting elk were at least seasonal residents of the Columbia Basin during the last 10,000 years.

## Introduction

It has commonly been assumed that the North American elk (*Cervus elaphus*) did not occupy the Columbia Basin of eastern Washington and north-central Oregon in post-glacial times. Bailey (1936) noted the absence of elk in the Columbia Basin or Oregon, an area that apparently separated the Rocky Mountain elk (*C. e. nelsoni*) of the Blue Mountains from the Roosevelt elk (*C. e. Roosevelti*) of western Oregon. Dalquest (1948) believed elk were poorly suited for life on the Columbia Plateau of eastern Washington, and that elk were probably never abundant anywhere in eastern Washington. Murie (1951) similarly thought that elk had never occupied the plains of the Columbia nor physiographically similar areas of southern Idaho and eastern Oregon. Bryant and Maser (1982) also noted the absence of elk in the Columbia Basin and other areas of eastern Washington.

These accounts of the apparent absence of elk from eastern Washington in general and the Columbia Basin in particular were based primarily upon the writings of early explorers and settlers. During the late 1800's and early 1900's many wildlife populations were at low levels throughout the western United States (Trefethen 1975), and an assessment of the original distribution of elk based upon these sources must be considered suspect. Indeed, not only elk were recorded as absent from this region, but bison (*Bison bison*) and pronghorn (*Antilocapra americana*) were also thought to have been absent from eastern Washington (Dalquest 1948). However, both of these species are now known to have occurred there prior to the settlement period (Osborne 1953). With the occurrence in recent historical time of elk in the Columbia Basin (Payne *et al.* 1975, Rickard *et al.* 1977), the hypothesized absence of elk from this region should be re-evaluated.

This paper reviews the archaeological evidence for the occurrence of elk in the Columbia Basin. Large amounts of animal skeletal material have been concentrated at sites associated with early human cultures in this area (Gustafson 1972). One limitation in a review such as this is the fact that early investigations were

concerned mainly with cultural artifacts, and faunal remains often lacked systematic treatment (Gustafson 1972, Lyman and Livingston 1983). Recent works have attempted to rectify this situation (Gustafson 1972, Kennedy 1976, Lyman and Livingston 1983), and along with earlier works that included faunal analyses, constitute the primary sources for this paper.

#### Columbia Basin Environment

The present climate of the Columbia Basin is arid with warm to hot summers, and cool winters (Franklin and Dyrness 1973). The principal vegetation types at present are shrub-steppe communities dominated by *Artemisia* and *Agropyron,* and grass communities dominated by *Agropyron* and *Festuca* (Daubenmire 1970). The post-glacial environment was, however, marked by climatic variation and associated changes in vegetation. The early post-glacial environment of the Columbia Basin (10,000-7,500 years B.P.) is believed to have been a period of cooler and more moist climate than the present, followed by a period (7,000-4,500 years B.P.) characterized by warmer and drier conditions than the present. An increase in moisture and decrease in temperature seems to have occurred about 4,500 years ago, and led to modern conditions in the Columbia Basin (Antevs 1955, Daugherty 1956). Changes in vegetation in response to these climatic shifts probably occurred; however, recent evidence suggests that this region has not supported extensive forest vegetation in post-glacial times (Gustafson 1972, Mack *et al.* 1976, Lyman and Livingston 1983). Pollen spectra representing the last 9,000 years in the Columbia Basin have been shown to resemble modern pollen spectra, suggesting a principally steppe-like environment (Mack *et al.* 1976). The preponderance of steppe fauna skeletal material found at most of the archaeological sites in the Columbia Basin also suggests primarily steppe vegetation for this region during post-glacial times (Gustafson 1972, Lyman and Livingston 1983).

#### Archaeological Record

Elk remains have been recovered from Marmes Rockshelter near the mouth of the Palouse River in Franklin County, Washington (Figure 1). In 7,500-10,000 year-old strata the remains of at least 5 elk were found associated with the remains of deer (*Odocoileus* spp.) and pronghorn (Gustafson 1972). Elk constituted 12.2 percent of the large mammals positively identified at the site, and were evidently an important source of food for the early occupants of the site. In 6,700-7,500 year-old strata elk represented over 16 percent of the large mammals recovered. The proportion of elk in identifiable large mammal remains decreased to approximately 6.5 percent in 4,000-6,700 year-old occupational strata. The remains of pronghorn were most abundant in these strata followed by deer and elk (Gustafson 1972, Kennedy 1976). Elk remains in 600-4,000 year-old strata were less abundant than in earlier strata; however, they still comprised about 2 percent of the large mammal remains.

The Cold Springs site (McNary Sites in Figure 1), located near the McNary Reservoir, was occupied 5,000-7,000 years B.P. by people that apparently relied upon fishing, hunting, and gathering in order of importance (Shiner 1954). The large mammal remains recovered at this site were mainly those of deer, elk, and mountain sheep (*Ovis canadensis*), although relative quantities were not reported.

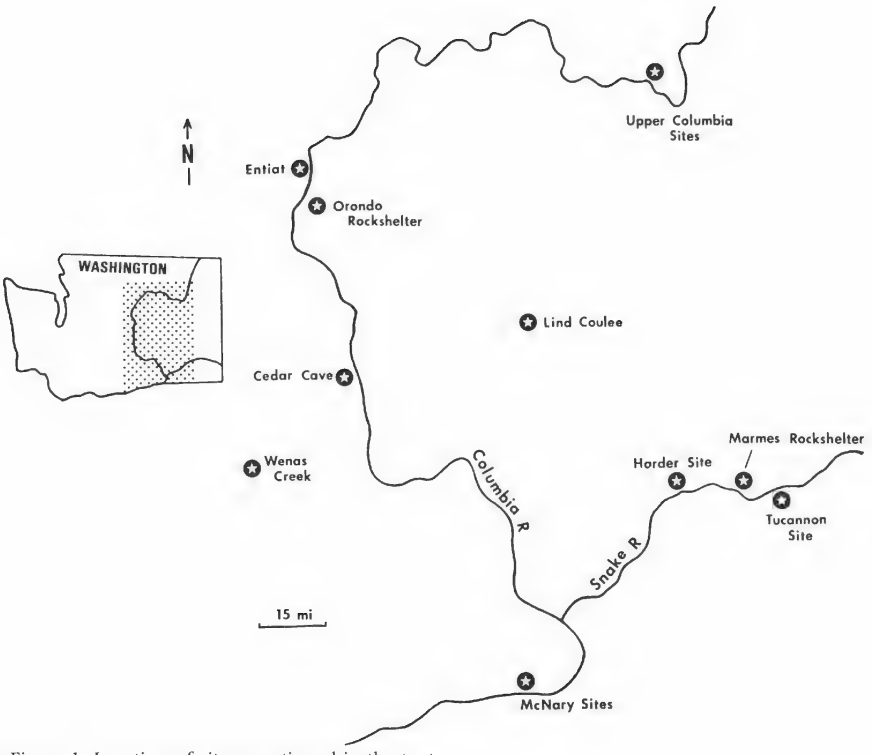


Figure 1. Location of sites mentioned in the text.

The Tucannon site (Figure 1), occupied approximately 2,500-4,000 years B.P., contained the remains of pronghorn, deer, and elk in order of abundance (Nelson *et al.* 1968, Kennedy 1976). Elk comprised approximately 10 percent of the large mammal remains recovered. Elk remains while not quantified were also noted at Wenas Creek, a 1,000-4,000 year-old site near the present city of Yakima, Washington (Figure 1) (Warren 1968). This site is near the east slope of the Washington Cascades where the occurrence of elk prior to historical introductions has been questioned (Pautzke *et al.* 1939, Dalquest 1948, Bryant and Maser 1982).

Elk remains, including teeth, mandible fragments, and a variety of post-cranial elements, were fairly abundant at the Harder site along the lower Snake River (Figure 1) (Kenaston 1966). This site was probably occupied between 187 and 687 A.D. by people that depended heavily upon hunting bison and elk.

Gunkel (1961) reported on elk remains from 2 sites in the Rocky Reach Reservoir region. At the 300-2,000 year-old Entiat site (Figure 1) the remains of deer, elk, and mountain sheep were identified. Elk remains, including a molariform tooth, were also recovered from the Orondo Rockshelter (Figure 1), a site occupied about 2,000 years ago (Gunkel 1961).

Collier *et al.* (1942) excavated a number of sites in the upper Columbia region between Grand Coulee Dam and the Canadian border (Upper Columbia Sites in Figure 1). These sites, occupied about 200-300 years ago, contained an unspecified number of elk bones, and several elk hides. Additionally, many elk teeth were recovered, and essentially all of them (222 of 223) were found at the southernmost sites near Grand Coulee Dam.

Osborne (1957) reported on 3 other excavations in the vicinity of the McNary Reservoir (McNary Sites in Figure 1) that were apparently used up to historic times. A culture dependent upon hunting deer and elk, fishing, and gathering was suggested by artifacts and faunal remains found at site 45-BN-53 (Shiner 1954, Osborne 1957). Elk remains at Berrian's Island, another recent site in the McNary region, used both for habitation and burials, included antler digging-stick tools, 10 elk canines, 1 elk incisor, and some long bones (Shiner 1954, Osborne 1957). At the Wallula site, which was contemporaneous with Berrian's Island, elk bones were reported as numerous, and elk antler wedges were also fairly common (Shiner 1954).

Elk appear to have been used by early inhabitants of the Columbia Basin during all of the major climatic periods spanning approximately 10,000 years (Table 1). Table 1 includes sites where only a few elk remains were found which provides further support for the hypothesis that elk have inhabited the Columbia Basin in the past.

TABLE 1. Summary of elk remains from Columbia Basin archaeological sites shown in Fig. 1.

| Site | Age (yrs. B.P.) | Comments | Reference |
|---|---|---|---|
| Marmes Rockshelter | 7500-10000 | numerous bones | Gustafson (1972) |
| Lind Coulee | 8000-9000 | 1 elk vertebra | Daugherty (1956) |
| Marmes Rockshelter | 6700-7500 | numerous bones | Gustafson (1972) |
| Cold Springs[1] | 5000-7000 | bones | Shiner (1954) |
| Marmes Rockshelter | 4000-6700 | numerous bones | Gustafson (1972) |
| Cedar Cave | 4000 | elk hair | Swanson (1956) |
| Tucannon Site | 2500-4000 | numerous bones | Nelson *et al.* (1968) |
| Wenas Creek | 1000-4000 | bones | Warren (1968) |
| Marmes Rockshelter | 600-4000 | numerous bones | Gustafson (1972) |
| Harder Site | 1000-2000 | numerous bones | Kenaston (1966) |
| Entiat | 300-2000 | bones | Gunkel (1961) |
| Orondo Rockshelter | 2000 | bones, tooth | Gunkel (1961) |
| Upper Columbia Sites | 200-300 | bones, teeth, hides | Collier *et al.* (1942) |
| 45-BN-53[1] | 2000-recent | bones | Osborne (1957) |
| Berrian's Island[1] | 2000-recent | teeth, bones | Osborne (1957) |
| Wallula Site[1] | 2000-recent | numerous bones | Osborne (1957) |

[1]McNary Sites in Figure 1.

#### Discussion

Marmes Rockshelter, one of few sites with strata representing all major climatic periods, has been used to infer changes in relative abundance of elk as related to climate (Gustafson 1972, Kennedy 1976). Both the overall proportion of elk remains, and the proportion of elk relative to pronghorn declined about 6,700 years ago (Gustafson 1972, Kennedy 1976). These phenomena correlate with the

hypothesized period of increased aridity in the Columbia Basin beginning about 7,000 years ago (Antevs 1955, Gustafson 1972, Kennedy 1976).

The major problem with interpreting the archaeological data concerns whether the elk skeletal material is indicative of the occurrence of elk in the vicinity of the occupational sites or whether it may have been carried in from surrounding forested regions. The preponderance of steppe fauna found at nearly all Columbia Basin sites studied suggests a cultural reliance upon local species (Gustafson 1972, Lyman and Livingston 1983). Elk remains have generally been associated with those of deer, bison, pronghorn, and sometimes mountain sheep (Osborne 1957, Gunkel 1961, Gustafson 1972, Lyman and Livingston 1983), species which could have been obtained in the Columbia Basin. Few species representing more mesic, forested regions have been identified at these sites. It would seem unlikely that prehistoric people would travel great distances to hunt elk without also bringing back evidence of other species. Long hunting treks also seem unlikely when local game could be obtained. The presence of cranial bones, distal long bones, vertebrae, and bones of the feet at many sites likewise argues against long distance transport of elk carcasses, as these elements probably were not carried far (Osborne 1953, Gustafson 1972). As previously noted, Collier *et al.* (1942) reported on Columbia River sites from Grand Coulee Dam north to the Canadian border, yet elk teeth and hides were more common in sites in the Columbia Basin than at more northerly sites where extensive forest vegetation was present.

The hypothesis that elk were not present in the Columbia Basin is not supported by the archaeological record. While no real measure of abundance can be made, the frequency of elk remains in Columbia Basin archaeological sites suggests elk were fairly common in this region (Gustafson 1972). It is not known if elk were year-round residents of the region, but they were at least seasonally available to early hunters. The presence of elk cannot simply be attributed to the occurrence of a different environment from the present, as elk were apparently present in both mesic and xeric steppes in the past. It is interesting to note that with the increase of elk in forested regions near the Columbia Basin in recent time, elk have begun to colonize areas of the basin where a vestige of original vegetation still exists (Rickard *et al.* 1977).

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# The Status of Persistentsepal Yellowcress in Washington

**Abstract**

The infrequently collected yellowcress *Rorippa columbiae* is abundant along the Hanford Reach of the Columbia River in south central Washington. A review of herbarium specimens suggests that the plants at the three known sites (south central Oregon; Columbia River, Washington; and Lava Beds National Monument, California) may be morphologically distinct. While the taxon appears to be abundant in Washington, more research is needed to clarify its status and to determine its present geographic distribution.

## Introduction

During an environmental survey of the potential disturbances from construction and operation of a nuclear power plant on the Hanford Site in south central Washington, it was discovered that a taxon of yellowcress growing along the Columbia River near the proposed construction site was on the Washington Natural Heritage Program list (1982) of endangered species and was also a candidate species for Federal Listing, Category 2, United States Fish and Wildlife Service (*Federal Register* 45:82480-82569, 15 December 1982). This species, *Rorippa calycina* (Engelm.) Rydb. var *columbiae* (Suksd. ex Robins) Rollins (see literature review below), a member of the Cruciferae, is a rhizomatous perennial with weakly ascending to erect stems, finely hirsute pinnatifid leaves, light yellow flowers, and oblong siliques. The known specimens are from only four general locations. This paper reports the present distribution of *Rorippa columbiae*, in Washington, with comments on its taxonomy and ecological and morphologic variation.

## Literature Review and Herbarium Records

Stuckey (1972) determined that *Rorripa calycina var. columbiae* Rollins is *R. columbiae* (Robbins) Howell based on fruit and flower pubescence and geographic distribution. Stuckey determined that the herbarium specimens from Montana, Nebraska and New Mexico are *R. calycina* and that the specimens from Washington, Oregon and California are *R. columbiae.* He also suggests that *R. columbiae* is a very old taxon that is restricted to the Columbia River basaltic plateau region of the Pacific Northwest.

Few collections of this plant are available. One specimen on file at the University of Washington herbarium (#5068), dated 19 May 1905, was collected by W. N. Suksdorf on the Columbia River near Bingen in Klickitat County. The Bingen specimens were collected "along the shore of the Columbia River," a site now almost certainly covered by the 48-mile-long pool behind Bonneville Dam. Stuckey (1972) was unable to relocate the species in the Bingen area in 1963. It is assumed that the original collection site and habitat were inundated by the approximately 30-ft rise in river water level at Bingen following completion of Bonneville Dam in 1938 (Jeff Hansen, U.S. Army Corps of Engineers, personal communication).

Seven specimens identified as *R. calycina* var. *columbiae* are on file at the Washington State University herbarium. Four of the specimens are from Washington; three were collected in the 1890's near Bingen by W. N. Suksdorf [#952 (type specimen, two sheets) and #5068], and one was collected in 1953 on the Hanford Reservation by J. J. Davis (#150). Three of the specimens are from Oregon; all were collected from Klamath County and dated 1901 (W. C. Cusick, #2717), 1951 (L. Constance, E. Molseed, and J. Weiler, #3680) and unknown (H. B. Schieferstein, no number). The final specimen is from California and was collected by J. W. Thompson (#13148) in the Lava Beds National Monument in Siskiyou County in 1936.

Four specimens are in the Battelle-Northwest ALE herbarium: two are dated 11 August 1953 and were collected on the Benton County side of the Hanford Reach near River Mile 365, and two are dated 8 August 1980 and were collected at the Hanford 100F gravel bar. No specimens were found at other likely herbaria, including Central Washington State University (Dr. William Barker, personal communication); Oregon State University (Dr. Kenton Chambers, personal communication); University of California at Riverside (Dr. Frank Vasek, personal communication); University of California at Los Angeles (David Verede, personal communication); and Lava Beds National Monument, Tule Lake, California (Gary Hathaway, personal communication). Also, this species was not included in a flora of Lava Beds National Monument compiled from 1936 to 1938 (Applegate 1938).

#### Field Observations

A field survey of the Hanford Reach and surrounding areas was made to document or verify the occurrence and extent of the distribution of *R. columbiae* in the vicinity of the proposed Skagit/Hanford Nuclear Project intake/discharge (River Mile 361.5). A second objective of the study was to identify and describe qualitatively the habitat in which the species occurs and the timing of its emergence relative to fluctuating river levels.

The yearly appearance of *R. columbiae* on the Hanford Reach during the growing season is dependent upon exposure of the appropriate habitat, which occurs when flows from upstream dams are reduced to less than approximately 100,000 cubic feet per second (cfs). Discharge from Priest Rapids Dam, the first dam upstream of the Hanford Reach, remained well above 100,000 cfs until late August 1982 (Dispatch Office, Grant County PUD, personal communication). Earlier inspections of the shoreline downstream of the dam revealed no suitable habitat. Flows at or less than 100,000 cfs occurred regularly beginning 23 August 1982.

The Benton County side of the Columbia River from River Mile 360 to 362 was inspected on 27 August and then weekly from 10 September through 8 October, and 22 October through 5 November 1982, to locate *R. columbiae* and to identify and note the extent of its habitat. Field observations were also made on 1 October 1982 on the Franklin County shoreline and at islands from River Mile 345 to River Mile 362 on the Benton County side from River Mile 364 to 365, and on the Grant County side at Vernita Bridge and Vernita Bar. On the same day, the east bank of the Columbia River at Sentinel Gap and Crab Creek, and the South Bank of the Snake River about one mile downstream from Ice Harbor Dam were inspected.

#### Results and Discussion

The field studies indicate that *R. columbiae* is common along the Hanford Reach (Figure 1). The species was observed on both banks of the river and on islands near River Mile 345 upriver to River Mile 362. *Rorippa columbiae* was observed on the Benton County side from River Mile 364 to 365 and in the vicinity of the Vernita Bridge on the Grant County side. No *Rorippa columbiae* was found at the Sentinel Gap, Crab Creek, or Snake River near Ice Harbor Dam sites.

The plants were observed in the vegetative stage in mid-September. The first flowers were observed on 24 September, and one plant was found in fruit on 29 October. The species was always found at or near the lower edge of the vegetated zone on the river bank where vegetation cover is generally sparse. The preferred habitat seems to be gently sloping gravel banks with wet silty soil beneath a layer of gravel. The gravel size is usually less than about 7 cm, although some plants were found among stones as large as 40 cm.

An important aspect of the habitat is the water level, which changes on a daily and seasonal basis. After late August 1982, the habitat was more or less continuously exposed. The presence of the species in previously flooded areas indicates it survives long periods of inundation. Before dams were built on the Columbia River, the water level probably decreased slowly during the summer, which gradually exposed the *R. columbiae* habitat and provided moist substrate early enough in the season to allow the species to flower and fruit before fall. Presently, water levels between Priest Rapids and McNary dams fluctuate as much as 2 m in a single day, resulting in frequent inundation. In addition, operation of these dams delays the seasonal drop of the water level in the Hanford Reach so that the *R. columbiae* habitat is exposed later in the season. The species is now subject to a growing season that is probably shorter and wetter than it had been before the dams were operational.

*Rorippa columbiae* appears adaptable to substrate disturbance. Before the presence of dams, spring floods probably scoured the river banks and sand bars. Disturbances were also common at the Hanford Townsite (Figure 1), an active farming community. During construction in the 1940's and 50's, considerable waste concrete, metal and other rubbish were dumped along the banks of the river. *Rorippa columbiae* is found today wherever suitable habitat exists—even among pieces of waste concrete.

A study of the limited herbarium material suggested that this species may be divided morphologically into three geographically separated variants. The plants

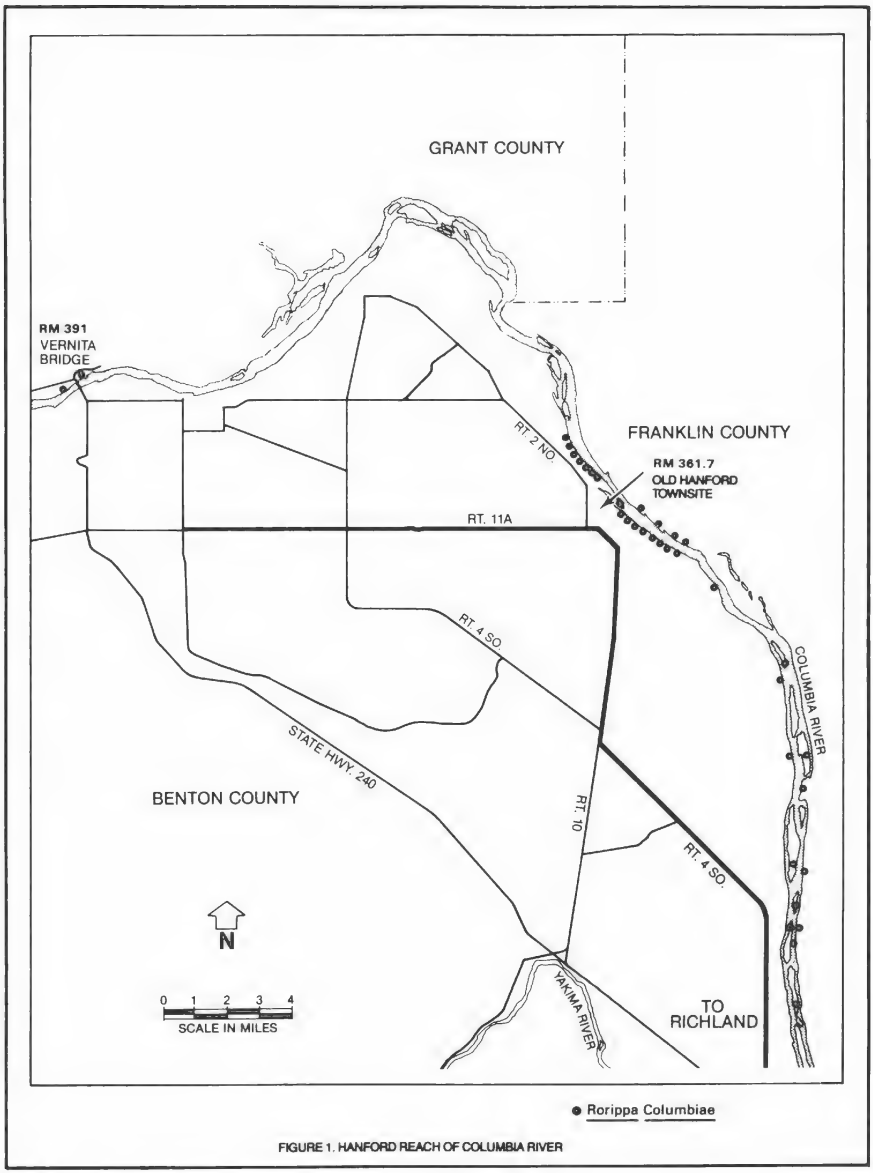


Figure 1. Hanford Reach of Columbia River. The dots indicate locations where yellowcress was growing.

along the Hanford Reach of the Columbia River and the Bingen collection are uniform in appearance, typically decumbent, with stems less than 30 cm long. In contrast, the single specimen from Lava Beds National Monument, collected

in 1936, is an erect, freely branched plant, spherical in habit, and approximately 30 cm in diameter and height. The material from the lakes in south central Oregon (Silver Lake, Swan Lake, and 10 miles west of Klamath Falls) is uniform in appearance, more or less decumbent, and intermediate in size and habit between the Columbia River and Lava Beds material. These characteristics are distinct enough that a casual observer can easily separate the specimens into the three groups: Lava Beds National Monument, south central Oregon, and Columbia River. We must immediately caution, however, that these observations are based on only a few collections (only one from Lava Beds National Monument) and that a careful study of a statistically valid number of plants is needed.

Our observations, together with the information from herbarium labels on known collections, indicate that *R. columbiae* occupies moist soil at the edge of a body of water except at Lava Beds National Monument in California. Here, according to the label, it occurs on lava slopes. However, it is likely that the single specimen from that area was collected on the shore of Tule Lake, which in 1936 when the specimen was collected, was within the boundaries of the Monument (Gary Hathaway, Lava Beds National Monument, personal communication). As with the morphological variation, we must caution that more studies are essential to confirm that *R. columbiae* is extant at previously collected sites and that its habitat is uniform throughout its range.

The species offers some interesting opportunities for detailed studies. Stuckey (1972) has suggested that the species may be very old and that the present distribution is relictual. If this is true, the geographic isolation between the Columbia River site(s) (Bingen *R. columbiae* may not presently exist) and the Oregon-California sites may be sufficient to have allowed divergent evolution to cause observable difference between these populations. To test this hypothesis would require collecting and propagating material from all sites and crossing the plants to obtain data on chromosomal compatibility between plants of the several sites. Chromosomal abnormalities such as rings or chains in the crosses would suggest that the specific status of the group was in question and that more consideration should be given to the preservation of a particular population because the "species" would not be as widespread as first thought.

Such studies on the distribution, morphology, cytogenetics, and ecology of *R. columbiae* are needed to accurately define the extent of vulnerability of this species. However, these studies are not necessary to document the abundance or uniformity of *R. columbiae* on the Hanford Reach of the Columbia River.

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# The Influence of Watershed Geology and Forest Roads on the Composition of Salmon Spawning Gravel

**Abstract**

The composition of stream gravels used for spawning by Pacific salmon (*Oncorhynchus* spp.) was examined in 12 streams in southwestern Washington State, whose watersheds have been actively managed for commercial timber production. The amount of fine sediment (<2 mm in size) was more closely correlated to the lithology and soils of the watershed than to forest management practices, specifically forest roads. None of the sampled stream reaches contained sediment in amounts considered to impair salmonid survival. Streams in watersheds dominated by basalt rock had a higher percentage of sand particles 0.5-2.0 mm and lower percentages of silt and clay (particles <0.063 mm) than did streams in watersheds dominated by siltstone and graywacke sandstone rock. A significant positive correlation was obtained between percentage of watershed area in sedimentary rock, and percentage of medium and fine sand and silt and clay particles in spawning gravels. Assessment of the potential of a watershed to produce fine sediment is possible by examination of basin geology and soils. Such an assessment should be made prior to estimating the sedimentation potential of spawning gravels.

## Introduction

Pacific salmon require clean, well-oxygenated, streambed gravels for successful spawning. Research has shown that as the percentage of fine sediment (<2 mm in size) in spawning gravel increases, mortality of salmonid eggs, embryos and alevins also increases, with survival to emergence from the gravel being sharply curtailed when fine sediment exceeds about 15 percent (Iwamoto *et al.* 1978). Cederholm and Salo (1979), and Cederholm *et al.* (1981) compared survival to emergence of coho salmon (*O. kisutch*) in a western Washington river basin to the amount of fine sediment in spawning gravels and identified a linkage between forest land management practices and spawning gravel sedimentation. They showed significant differences between the percentages of fine sediment (<0.85 mm) in spawning gravels located below sections of recently harvested forest and gravels in undisturbed old-growth control areas. Watershed characteristics such as geology, soils, climate, and hydrology were assumed to be uniform throughout the river basin.

Because watershed erodibility and the composition of stream gravels is dependent upon the lithology and soils of the drainage basin and the specific climatic, vegetative, topographic, and hydrologic factors present (Miller 1958, André *et al.* 1961), the specific effect that forest management activities will have on gravel composition, and in turn on salmon production, is often highly variable and difficult to predict. To effectively measure and interpret forest practice effects on gravel

composition, and to understand geographical variation, one must establish a baseline which considers factors such as soils and geology of the drainage basin in addition to past and present forest management practices. This study examined the grain size distribution of spawning gravels in managed forested watersheds of differing lithology and soils, with the objective of assessing the relative influence of watershed geology and logging roads on spawning gravel composition.

#### Site Characteristics

Twelve salmonid spawning streams in southwestern Washington were chosen for study. The watershed of each stream represented what we believed to be the average geologic, soil, and topographic condition of privately owned commercial forest land in southwestern Washington. Each watershed had been harvested from 2 to about 40 years ago and contained various stages of second growth coniferous forest of Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), although riparian areas were dominated by red alder (*Alnus rubra*). Cable logging was the dominant harvest system used, with tractor-skidder methods utilized on some of the slopes under 20 percent gradient. Logging road densities were average for the region and age of harvest. The minimum road density occurred in a basin harvested by railroad, and the maximum in an area dominated by long, steep, highly dissected slopes (Table 1).

Eight of the 12 study streams were located in the Willapa Hills physiographic province of southwestern Washington. The remaining four streams drained portions of the Cascade foothills southwest of Mt. St. Helens and were unaffected by the recent volcanic activity. All streams were tributary to either Willapa or Grays Harbors or the lower Columbia River. The maritime climate is characterized by relatively dry, cool summers and wet, mild, rain-dominated winters. Annual precipitation ranges from approximately 127 cm to over 280 cm. Snow accumulations are small and of short duration (Phillips 1964).

Basaltic sandstone of the Astoria formation of mid-Miocene age, and Oligocene age silt and claystone of the Lincoln Creek formation (Pease *et al.* 1957, Gower *et al.* 1965) comprised the majority of the sedimentary rocks present. Submarine basalt of Eocene age (Wagner 1967) and other mixed volcanics of basaltic and andesitic composition comprised the other rock types. All of the rock types present were highly weathered in their upper portions, giving rise to deep, moderately fine-textured soils (Duncan and Steinbrenner 1969, 1971; Steinbrenner and Gehrke 1966).

The topography associated with the rocks and soils composing the watersheds is best described by the drainage density, expressing the overall texture of the watersheds, and the relief ratio, a measure of the overall basin steepness (Table 1). Both of these values are useful in comparing relative erosion potentials between drainage basins.

All streams were of fourth order (Strahler 1957) at the point sampled, with gradients averaging about 0.8 percent. Estimated bankfull discharge (Dunne and Leopold 1978) ranged from 30 $m^3/s$ in the largest watershed to approximately 4 $m^3/s$ in the smaller watersheds. Road-related and natural landslides had entered all of the streams at various times, although no slides had entered any of the streams above the sample points during the year prior to sampling. The number of locations

TABLE 1. Characteristics of Sampled Watersheds

| | | | | | Rock Type | | Soils | | | Roads | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Watershed Area† | Drainage Density | Relief§ Ratio | Est. Bank-Full Discharge | Sedimentary§ | Volcanic | Avg. Depth | Sand§ | Silt§ and Clay | Length | Road§ Density | Direct§ Entry Density | Watershed Area in Road |
| | ($km^2$) | (km/$km^2$) | height/length | $m^3/s$ | (%) | (%) | (M) | (%) | (%) | (km) | (km/$km^2$) | (no./km) | (%) |
| Bernier | 7.68 | 3.53 | 0.101 | 4.23 | 83 | 17 | 1.10 | 20.9 | 79.1 | 21.35 | 2.78 | 1.07 | 2.5 |
| Delezene | 28.29 | 4.49 | 0.063 | 14.23 | 83 | 17 | 1.10 | 22.4 | 77.6 | 60.69 | 2.14 | 0.76 | 1.9 |
| Swem | 14.92 | 3.49 | 0.078 | 7.85 | 65 | 35 | 1.20 | 37.5 | 62.5 | 45.70 | 3.06 | 1.85 | 3.0 |
| Forks | 11.22 | 4.33 | 0.107 | 6.02 | 52 | 48 | 0.96 | 33.8 | 66.2 | 39.61 | 3.53 | 1.06 | 3.0 |
| Eight | 15.02 | 11.23 | 0.075 | 7.90 | 41 | 58 | 1.10 | 36.8 | 63.2 | 57.34 | 3.82 | 1.41 | 4.0 |
| Fall | 32.68 | 4.39 | 0.097 | 16.27 | 39 | 61 | 1.30 | 35.3 | 64.7 | 68.35 | 2.09 | 1.32 | 2.0 |
| S. F. Chehalis | 15.60 | 3.45 | 0.113 | 8.18 | 22 | 78 | 1.10 | 52.2 | 47.8 | 25.62 | 1.64 | 0.39 | 1.5 |
| S. F. Willapa | 17.53 | 3.85 | 0.074 | 9.12 | 0 | 100 | 0.93 | 43.5 | 56.5 | 60.59 | 3.46 | 0.58 | 3.0 |
| Abernathy | 32.14 | 3.37 | 0.065 | 16.02 | 0 | 100 | 1.20 | 34.2 | 65.8 | 57.34 | 1.78 | 0.42 | 1.6 |
| Mulholland | 41.99 | 3.15 | 0.073 | 20.54 | 0 | 100 | 1.10 | 37.0 | 63.0 | 74.11 | 1.76 | 1.50 | 1.6 |
| Coweeman | 63.94 | 3.93 | 0.090 | 30.38 | 0 | 100 | 1.00 | 40.5 | 59.5 | 114.68 | 1.79 | 1.73 | 1.6 |
| Thrash | 9.32 | 5.39 | 0.120 | 5.07 | 0 | 100 | 0.70 | 41.1 | 58.9 | 34.83 | 3.74 | 1.69 | 3.3 |
| Average | 24.19 | 4.55 | 0.088 | 12.15 | | | 1.07 | 36.27 | 63.73 | 55.02 | 2.63 | 1.15 | 2.42 |

†Watershed area upstream of sample location.
Direct entry density refers to number of road sediment entry points/km of road.
§Independent variables used in final regression analysis.

upstream of the study sites where sediment originating from road surfaces, ditches, and back slopes entered directly into the streams varied from 0.39 to 1.85/km of road and averaged 1.15/km for the 660 km of road inventoried within the 12 drainage basins.

#### Methods

Three known salmonid spawning riffles per stream were chosen and samples collected through use of a liquid $CO^2$ frozen core sampler similar in design to that of Walkotten (1976), which was found by Shirazi and Seim (1979) to be superior to other methods.

Following the sampling guidelines of Shirazi *et al.* (1979), we selected three locations within each spawning riffle according to the preferred within-riffle spawning location outlined by Reiser and Bjornn (1979). Because coho salmon and steelhead trout (*Salmo gairdneri*) were the principal anadromous species in the study sites, sample depth was limited to the upper 30 cm of spawning gravel.

Since indexing of survival to emergence was the primary consideration, samples were collected as close to the spring emergence period (March-April) as possible. Adams and Beschta (1980) found that the pattern and magnitude of hydrologic events caused temporal variation in spawning gravel composition; therefore, we concentrated our time of sampling to avoid influence of additional hydrologic events.

Samples were dry sieved in the laboratory using Tyler sieves with 64, 16, 8, 2, 0.5, and 0.063 mm openings. Shirazi, Lewis, and Seim (1979) found dry sieving to be superior to the wet method since considerable bias could be introduced as a result of water bonding of particles $<4$ mm in size. Individual size classes were expressed as a percentage by weight of the total sample. The percentage of each size class was averaged for each riffle and a mean calculated for each stream.

In order to compare our results with other studies where volumetric analyses were used, the density of the gravels was determined by dividing the dry weight of each size class in grams by the displaced volume of water in $cm^3$. With the gravel density thus determined, the conversions given by Shirazi and Seim (1979) were used to compare volumetric to gravimetric analysis.

The percentage of sand (2.0-0.063 mm) and silt plus clay ($<0.063$ mm) in the soils of the watersheds was computed from soil surveys (Duncan and Steinbrenner 1969, 1971; Steinbrenner and Gehrke 1966).

Stepwise, multiple linear regression techniques (Helwig 1979) were used to relate percentage of sediment particle sizes to watershed parameters, including drainage density, relief ratio, percentage sedimentary rock in the watershed, and percentage sand, silt, and clay in the soils. Management variables examined included road density, direct entry point density, and percentage of watershed area in roads and landings (Table 1).

#### Results

Significant differences in the percentages of fine sediments existed among the streams ($P \pm 0.05$, 2-way ANOVA). Examination of individual size classes by stream showed significant differences in the percentages of sediment $<2$ mm diameter among streams draining sedimentary and volcanic rock watersheds (Table 2).

TABLE 2. Particle Size Distribution of Spawning Gravel for Sedimentary and Volcanic Rock Watersheds

| | | % of Total | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sedimentary Rock Watersheds | | | | | |
| Stream | % Sed-Rock | Coarse Gravel 64-16 (mm) | Medium Gravel 16-8 (mm) | Fine Gravel 8-2 (mm) | Coarse Sand 2-0.5 (mm) | Medium and Fine Sand 0.5-0.063 (mm) | Silt and Clay <0.063 (mm) |
| Bernier | 83 | 54.14 | 15.87 | 14.53 | 7.19 | 6.73 | 1.54 |
| Delezene | 83 | 48.94 | 19.80 | 17.56 | 8.08 | 4.69 | 0.93 |
| Swem | 65 | 63.52 | 14.32 | 10.33 | 5.15 | 5.94 | 0.74 |
| Forks | 52 | 64.41 | 13.50 | 11.71 | 6.24 | 3.37 | 0.77 |
| Eight | 41 | 69.87 | 13.63 | 7.72 | 4.14 | 4.15 | 0.49 |
| Fall R. | 39 | 63.72 | 14.65 | 11.82 | 4.72 | 4.52 | 0.57 |
| S. F. Chehalis | 22 | 61.93 | 13.95 | 12.99 | 5.29 | 4.98 | 0.86 |
| Mean | | 60.85 | 15.11 | 12.38 | 5.83 | 4.91 | 0.84 |
| Std. Error | | 2.65 | 0.84 | 1.18 | 0.53 | 0.42 | 0.13 |
| | | Volcanic Rock Watersheds | | | | | |
| Stream | % Sed-Rock | 64-16 (mm) | 16-8 (mm) | 8-2 (mm) | 2-0.5 (mm) | 0.5-0.063 (mm) | <0.063 (mm) |
| S. F. Willapa | 0 | 60.92 | 15.98 | 14.22 | 5.58 | 2.77 | 0.53 |
| Abernathy | 0 | 56.23 | 15.24 | 15.87 | 8.72 | 3.43 | 0.51 |
| Mulholland | 0 | 62.04 | 13.80 | 14.18 | 7.07 | 2.48 | 0.43 |
| Coweeman | 0 | 52.49 | 18.63 | 17.94 | 7.71 | 2.75 | 0.48 |
| Thrash | 0 | 71.67 | 11.29 | 9.39 | 4.71 | 2.43 | 0.49 |
| Mean | | 60.66 | 14.98 | 14.32 | 6.76 | 2.77 | 0.49 |
| Std. Error | | 3.26 | 1.21 | 1.41 | 0.72 | 0.18 | 0.02 |

Because of the differences in amounts of sediment in the fine grain sizes (<2 mm) among streams (Table 3), and the importance of this size fraction to salmonid egg survival, groupings of <2.0, 2.0 to 0.063, <0.5 and <0.063 mm sizes were used in all analyses.

The variable having the strongest association with sediment <0.5 mm in size, and with the silt plus clay fraction, in the spawning gravels was found to be the percentage of basin area in sedimentary rock (Table 4). This was expected since the fairly high amount of fine sand, silt, and clay in the soils (the primary sediment sources in the watersheds) has resulted from weathering of fine-grained, argillaceous, graywacke sandstones, and siltstones.

The dominant rock type composing the spawning gravels was determined for each sample. The more resistant basaltic rocks were found to dominate each spawning riffle (Table 5). The soft sedimentary rocks break down rapidly in the streams, forming few gravels >8 mm in size. Similar rapid decomposition of sedimentary rock gravel was noted in the study area by Glancy (1971). As the percentage of sedimentary rock in the riffle increased the amount of sediment finer than 0.063 mm in the spawning gravel also increased ($r^2 = 0.86$).

In order to determine the relative importance of watershed geology vs. forest road influences, the highly significant geologic factors such as rock type and soils were sequentially removed from the statistical analysis. Subsequent tests revealed no statistically significant single-variable correlations between any forest road parameter and spawning gravel composition.

TABLE 3. Particle size distribution of spawning gravels—size fraction <2 mm in sedimentary and volcanic rock watersheds

| Stream | 2 to 0.5 (mm) | 0.5 to 0.063 (mm) | <0.063 (mm) |
|---|---|---|---|
| **Sedimentary Rock Watersheds** | | | |
| Bernier | 46.51 | 43.53 | 9.96 |
| Delezene | 58.98 | 34.23 | 6.79 |
| Swem | 43.53 | 50.21 | 6.26 |
| Forks | 60.11 | 32.47 | 7.42 |
| Eight | 47.15 | 47.27 | 5.58 |
| Fall R. | 48.11 | 46.08 | 5.81 |
| S. F. Chehalis | 47.53 | 44.74 | 7.73 |
| Mean | 50.27 | 42.64 | 7.07 |
| Std. Error | 2.46 | 2.53 | .56 |
| **Volcanic Rock Watersheds** | | | |
| S. F. Willapa | 62.84 | 31.19 | 5.97 |
| Abernathy | 68.88 | 27.09 | 4.03 |
| Mulholland | 70.94 | 24.85 | 4.21 |
| Coweeman | 70.47 | 25.14 | 4.39 |
| Thrash | 61.73 | 31.85 | 6.42 |
| Mean | 66.97 | 28.02 | 5.00 |
| Std. Error | 1.25 | 1.48 | .49 |

TABLE 4. Correlations between spawning gravel grain size classes, percent of watershed in road, road density, direct entry points and percent of area in sedimentary rock. Best two-variable correlations are also shown.

| Grain Size | % Area in Road | | Road Density | | Direct Entry Density | | % Area in Sedimentary Rock | |
|---|---|---|---|---|---|---|---|---|
| (mm) | $r^2$ | F | $r^2$ | F | $r^2$ | F | $r^2$ | F |
| <2 | 0.033 | 0.35 | 0.023 | 0.21 | 0.097 | 1.07 | 0.41 | 6.95* |
| 2 to .063 | 0.001 | 0.01 | 0.014 | 0.13 | 0.20 | 2.55 | 0.39 | 6.41* |
| <.5 | 0.001 | 0.01 | 0.023 | 0.21 | 0.020 | 0.21 | 0.68 | 21.38* |
| <.063 | 0.036 | 0.37 | 0.033 | 0.34 | 0.059 | 0.63 | 0.65 | 20.29* |

Significant Two-Variable Combinations

| Grain Size | % Sedimentary Rock + % Sand in Soils | | % Sedimentary Rock + % Silt + Clay in Soils | | % Sedimentary Rock + Direct Entry Density | |
|---|---|---|---|---|---|---|
| (mm) | $r^2$ | F | $r^2$ | F | $r^2$ | F |
| <.063 | - | - | 0.68 | 10.69** | 0.75 | 15.11** |
| <.5 | 0.72 | 11.49** | - | - | | |

*P≤0.05
**P≤0.01

TABLE 5. The type of rock composing the spawning riffles.

| Stream | Watershed Area in Sedimentary Rock (%) | Within Riffle Rock Type | |
|---|---|---|---|
| | | Sedimentary (%) | Volcanic (%) |
| Bernier | 83 | 18.5 | 81.5 |
| Delezene | 83 | 13.1 | 86.9 |
| Swem | 65 | 0.9 | 99.1 |
| Forks | 52 | 2.5 | 97.5 |
| Eight | 41 | 3.0 | 97.0 |
| Fall R. | 39 | 2.0 | 98.0 |
| S. F. Chehalis | 22 | 7.6 | 92.3 |
| S. F. Willapa | 0 | 0 | 100 |
| Abernathy | 0 | 0 | 100 |
| Mulholland | 0 | 0 | 100 |
| Coweeman | 0 | 0 | 100 |
| Thrash | 0 | 0 | 100 |

The strongest two-variable correlations were found when direct road surface sediment entry point density was combined with percentage of sedimentary rock (Table 4). Direct entry point density, a measure of the number of road surface sediment entry points per unit road length upstream of the sample sites, was best correlated with particle sizes $<0.063$ mm, the silt and clay fraction. Although silt and clay comprise some 63 percent of the soils in the basins, this is also the size fraction most commonly generated from road surfaces in response to truck traffic (Sullivan and Duncan 1981, unpublished data; Bilby, unpublished manuscript).

#### Discussion

Every spawning riffle or segment of stream is an integration of upstream geologic characteristics, climate, and land use (Schumm 1977). Before specific land use practices can be evaluated, their effect in relation to geologic and hydrologic factors in the drainage basin must be determined. Establishment of watershed erosion potential is essential to the quantification of land use impacts. Cederholm *et al.* (1981) showed that the percentage of sediment $<0.85$ mm in spawning gravels increased in proportion to basin area affected by timber harvesting and roads. This relationship was not observed in the streams sampled in this study. Sediment $<2.0$ mm averaged 11 percent of spawning gravel and ranged from 15 percent in a basin composed of 83 percent sedimentary rock and a high incidence of stream entry landslides, to 8 percent in another basin composed of 100 percent volcanic rock, high road densities and past stream entry landslides (Table 1).

Adams (1980) noted spatial and temporal variation in the composition of streambed gravels and found watershed hydrology, especially magnitude of peak flows, to be of particular importance. Adams' analysis showed that while sediment from roads may temporarily increase the amount of fine sediment in stream gravels, such increases tend to be temporary and flush with the next high flow.

Although the influence of roads on the fine sediment ($<0.063$ mm) content of spawning gravel was demonstrated by combining road surface sediment entry points with basin rock type, spawning gravel composition in the study streams

was more closely related to basin geology than roads. For example, of the two streams most heavily impacted by accelerated sediment input from roads, primarily via landslides, Thrash Creek, a basin composed of 100 percent volcanic rocks and shallow soils, had spawning gravels with the lowest fine sediment content of those sampled (Table 1). Bernier Creek had also experienced a high frequency of stream entry landslides and contained the highest percentage of spawning gravel sediment finer than 2 mm. The Bernier Creek basin is composed of 83 percent highly weathered, argillaceous, graywacke sandstones, and soils in excess of one meter deep containing 79 percent silt plus clay. It also has a lower road density and fewer direct entry points per unit road length than Thrash Creek. Some temporal variation in gravel composition in relation to climatic conditions and land use activities is expected; however, watershed geology determines the type, character, and potential amount of sediment in the stream system and to some degree the influence a specific road network could have on sediment type and supply.

Fifty years ago, Middleton (1930) classified soils into broad erosion potential groups based on their silt plus clay content. Anderson (1951) expanded Middleton's erosible categories and expressed them in terms related directly to sediment production from whole watersheds. In his analysis, Anderson found that in areas of youthful soils, such as occur in western Washington, soil "erosibility" was dependent on drainage basin lithology.

Although there was no opportunity to determine the fine sediment content of the riffles prior to watershed roading and harvest, it is important to note that only one of the streams, Bernier Creek, approached the 15 to 20 percent fine sediment level (<0.8 mm) found detrimental to survival of Pacific Northwest salmonid embryos by Koski (1966), Hall and Lantz (1969), Burns (1972), Phillips *et al.* (1975), Cederholm and Salo (1979), Tappel and Bjornn (1980).

An assessment of the fine sediment production potential between watersheds is possible by considering basin lithology and soils. Such assessments should be made prior to estimating the impact of forest management practices on spawning gravel quality and should aid in tailoring road location, design, and maintenance to fit specific watershed characteristics.

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# Grasshoppers on Snow in the Wallowa Mountains, Oregon

**Abstract**

In 1979 the Pacific Northwest experienced one of the worst grasshopper outbreaks on record. An altitudinal extension of that infestation was observed in the Wallowa Mountains, Oregon, where grasshoppers were found on snow at altitudes of 2,450 to 2,925 m in early July on the north side of Eagle Cap. Observations made for seven out of the last thirteen years indicate that 1979 was the only year in which grasshoppers were present. They are assumed to be the migratory grasshopper, *Sanguinipes melanoplus,* the major species of the lowland infestation, and to have come from adjacent agricultural regions to the south. Movement was through a series of short sporadic flights by small groups or individuals rather than through massive migration.

The movement of lowland grasshoppers to high altitudes provides food for resident animals and a fringe of pioneers which apply upward pressure for establishment of the species at the highest altitude possible. Their presence opens up new genetic and ecological opportunities and demonstrates the essential connectivity between mountains and lowlands.

## Introduction

In 1979 the Pacific Northwest experienced one of the worst grasshopper infestations on record. High grasshopper populations occurred throughout the Columbia Plateau, from the base of the Cascades to southeast Washington and east central Idaho. The worst stricken areas were in north central and northeast Oregon where up to 300 grasshoppers per square meter (yard) were recorded (Figure 1). The number normally considered excessive and requiring control is eight per square meter (yard) (USDA 1980). This great grasshopper outbreak apparently resulted from a steady buildup in the population over several years aided by warm springtime conditions, culminating in the spring of 1979, which provided a persistent dry warming trend that was ideal for grasshopper survival (Oregon Agri-Record 1979, p.6).

This report deals with a related aspect of that infestation—the presence of grasshoppers at high altitudes in the Wallowa Mountains during the same time. The Wallowas, located in extreme northeastern Oregon, are the highest and most rugged section of the Blue Mountains. As such they are ideally situated to test the significance and effect of altitude on lowland grasshopper distributions since the infestation surrounded the mountains on every side (Figure 1).[1]

[1]A peculiarity exists in the way grasshopper densities are mapped by the USDA. There are two counts made: one is of nymphs in the spring or early summer, the other is of adults in late summer or early fall. The nymphal survey is used to make decisions to spray that season whereas the adult survey is useful for indicating areas of potential problems for the next season. While these are both practical approaches to the problem, the information gathered and the maps that result leave a great deal to be desired. The nymphal surveys are usually not published (or even mapped). The map shown in Figure 1 is based on the adult survey made in August and September, 1979 (called "1980 grasshopper outlook"). It is not a true picture of grasshopper densities during 1979, however, since it does not show the areas that were sprayed earlier that summer (which were also heavily infested areas). This explains why no grasshoppers are shown on the north side of the Wallowas, because this was one of the principal spray areas in 1979. As a geographer interested in the collection and mapping of data, I find this approach far from satisfactory. Nymphal surveys and spray areas should also be included to show a more complete picture of grasshopper densities during a given year.

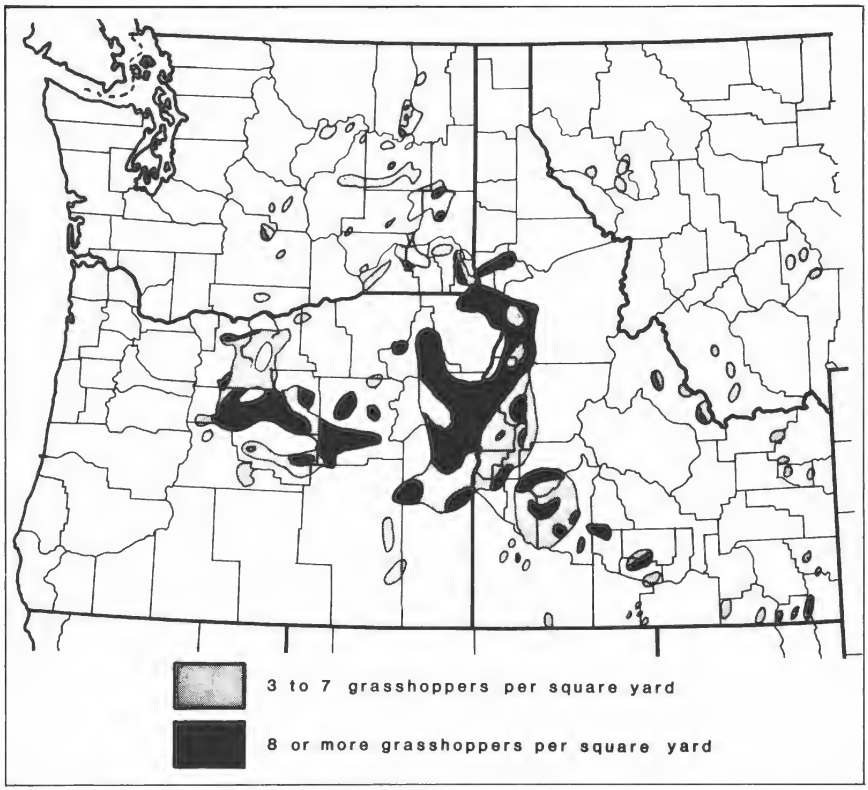


Figure 1. Adult grasshopper densities in the Pacific Northwest during late summer and fall, 1979 (See Footnote 1) (USDA, 1980).

**Study Area**

The Wallowas are a circular dome shaped area approximately 60 km in diameter rising to an elevated core of 3,000 m. They are comprised of sedimentary and volcanic rocks overlying a granitic batholith which has been exposed at the center by strong glacial erosion (Smith and Allen 1941). Glacial valleys radiate outward in all directions and at the hub is Eagle Cap, 2,925 m high. On the north side of Eagle Cap is the Lake Basin, a broad deep valley with strong ice scoured surfaces and paternoster lakes. This is the heart of the Eagle Cap Wilderness Area and the focus of this study (Figure 2).

The Wallowas have a continental climatic regime with a summer precipitation maxima. Enterprise, located immediately to the north of the range, receives an average annual precipitation of 345 mm (NOAA 1980). The mountains receive considerably more than this, of course, from both summer thunderstorms and winter snow. The Wallowas are surrounded by semiarid steppe, which under natural conditions, support bunchgrass (*Agropyron spicatum, Festuca idahoensis*) and sagebrush (*Artemisia tridentata*). Ponderosa pine (*Pinus ponderosa*) begins at about 900 m grading upward into Douglas fir (*Pseudotsuga menziesii*) and Grand

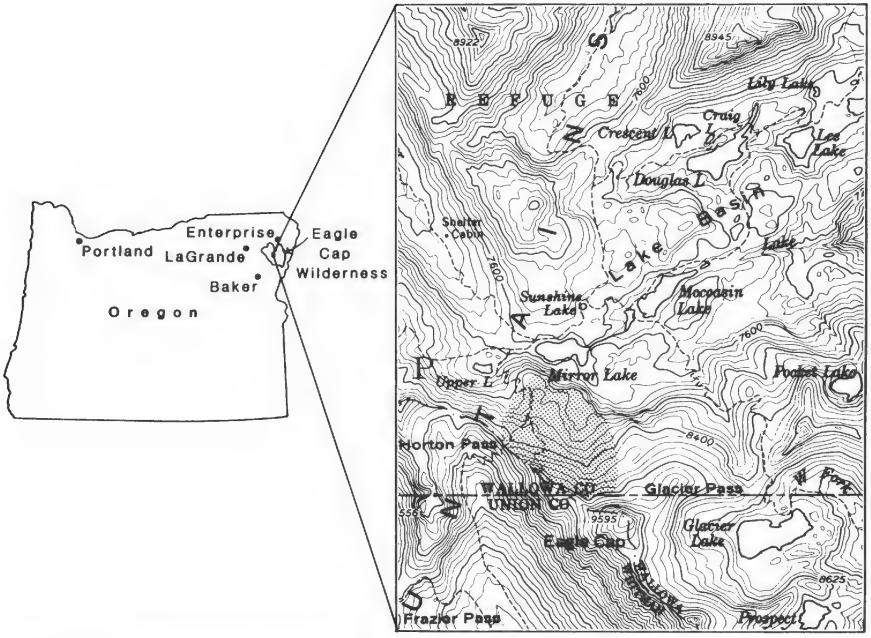


Figure 2. Location and topography of Lake Basin within Eagle Cap Wilderness, Wallowa Mountains. Dot pattern denotes main areas of grasshopper occurrence. Base map is U.S.G.S. Eagle Cap Quadrangle, 15 minute series. Contour interval is 24.4 m (80 ft.) and horizontal distance across map is 4.5 km (2.8 miles).

fir (*Abies grandis*). The Subalpine zone begins at 2,100 m consisting of Subalpine fir (*Abies lasiocapa*), Whitebark pine (*Pinus albicaulis*), and Engelmann Spruce (*Picea engelmanni*). It is difficult to establish an altitude for the upper timberline in the Wallowas because of the prevalence of bare rock surfaces, which is as much a limiting factor as is altitude. Trees grow entirely to the tops of the peaks in favorable sites and would go higher if the mountains were higher (Price 1984). Subalpine meadows occur throughout the upper reaches of the Wallowas, however, and a well developed alpine flora exists (Mason 1975).

For seven out of the last thirteen years I have spent one week to ten days in early July camped in the upper Lake Basin with students from the geography summer field camp at Portland State University. This has given me ample opportunity to observe conditions there on a continuing basis. The Lake Basin is 3 km wide by 6 km long oriented northeast-southwest with valley floor elevations ranging from 2,100 to 2,300 m (Figure 2). The basin heads in a large amphitheater below Eagle Cap where it is rimmed by steep headwalls on the south and west. The prevailing southwesterly wind during winter sweeps snow off the surrounding ridges and deposits it in the Lake Basin. Consequently, the Mirror Lake Snow Survey Station located in the basin immediately below Eagle Cap at 2,500 m records one of the heaviest snow accumulations in Oregon. On May 1, 1979, there was 4,445 cm of snow on the ground, which is about average for this time of year (U.S. Dept.

Agri. 1979). Stormy weatheer typically continues into May and June and maintains a thick snow cover in the upper Lake Basin until early July when lake ice is just beginning to melt (Price 1984). This, then, is the setting in which the following observations were made.

### Methods

Grasshoppers were first observed on July 6 on the snow in the lee of Eagle Cap from about 2,450 m upwards. This was early morning and the snow was still frozen. The grasshoppers were lethargic and scarcely moving. When we picked them up they remained motionless. By afternoon, however, the snow was soft and slushy and many of the grasshoppers were active and occasionally hopped across the snow. They could still be easily caught but now if you opened your hand they would jump out. The grasshoppers were typically located in sun cups in the snow and were often sunken into small vertical depressions because of their darker color and greater absorptivity. Almost all were alive on this active snow surface indicating that they had not been there long. There was no food on the snow for them to eat so presumably most would die within a few days. Several small birds were observed harvesting the grasshoppers as well as other insects on the snow.

Unlike the north-facing slope, where blow-over snow accumulates and the shadow climate protects it from melting, the broad and gentle south sloping summit of Eagle Cap at 2,925 m is normally snow-free by early July (as it was in 1979). Scattered clumps of shrubby Whitebark pine grow up to 1 m high on the summit but most of the surface is a windswept fell field supporting sparse alpine mat and cushion plants (Price 1984).

A systematic search of the upper summit on July 6 revealed only three grasshoppers. In contrast with those on the snow, these were extremely active and difficult to catch. The weather on this day was sunny between the convectional clouds and occasional showers so the soil surface was warm. The wind was southwesterly at 15-30 km per hour. I tried to catch one of the grasshoppers and it quickly jumped with the wind to a height of about 1 m and was whisked over the summit headwall, presumably to land on the snow some 300-400 m below. No evidence of nibbling on the plants or any other evidence of damage from grasshoppers was observed.

The next day I revisited the snowfield and began more systematic sampling. On the 1.5 km hike from Moccasin Lake to Mirror Lake I saw only two grasshoppers along the trail but once above Mirror Lake on the snow they became more common (Figure 2). By 2,450 m the density of grasshoppers increased to 1 per 10 m in a walking transect up the slope covering a swath 6 m wide. By 2,600 m, and close to the north facing headwall of Eagle Cap, the density was greatest—about 1 grasshopper every 2 m in a swath 6 m wide (a five fold increase). Once atop the broad windswept ridge, however, only occasional grasshoppers were sighted. At the same time the students working on various projects throughout the Lake Basin, observed occasional grasshoppers around Moccasin Lake, Mirror Lake, and the upper Lostine Valley. None was seen in the Lower Lake Basin although five people were down there with instructions to look. Clearly, grasshoppers were most abundant on the snow to the immediate lee of Eagle Cap (Figure 2).

**Results and Discussion**

All of the grasshoppers were adults with well developed wings. Several specimens were collected for identification but were lost. They are, nevertheless, assumed to be the migratory grasshopper, *Melanoplus sanguinipes,* the dominant representative of the lowland infestation (Goeden 1979). Another species, *Melanoplus alpinus,* lives naturally up into the subalpine zone of the Wallowas but it is a somewhat smaller creature compared to the larger yellow and reddish-brown grasshoppers I observed. The observational period was early July and far too early for the appearance of *Melanoplus alpinus,* which does not normally mature until mid-August (Banfill and Brusven 1973). Interestingly, while most lowland grasshoppers complete their life cycles in one year, this highland species may take three years for complete development (Kreasky 1960).

A final inference is that 1979 was the only year out of the following sequence of years—1970, 71, 73, 74, 78,79, 83—that grasshoppers were observed on snow in the Wallowas. I have long been intrigued by the "aeolian zone" and actively search for arthropods on alpine snow. Consequently, I can say with confidence that this was the only year of the seven that grasshoppers were present on snow at the time I was there in early July. The implications are clear; their presence in 1979 seems to be related to their great abundance in the surrounding lowlands. The question that now arises is: "What were the grasshoppers doing at this altitude?"

The presence of lowland grasshoppers at high altitudes is not particularly unique. Alexander (1951, 1964) reports that lowland grasshoppers can be observed on alpine snow in the Front Range of the Colorado Rockies almost every summer, especially where the mountain area extends close to or is surrounded by lowlands. This annual visitation by grasshoppers is accomplished primarily by individual stragglers or groups of stragglers which have flown or have been carried there by the wind.

Weather conditions in continental mountains are ideal during summer for upward movement of insects since the air typically moves upslope during the day and down at night. Grasshoppers would only be active during the day since low night temperatures would render them inactive. This correlates nicely with Alexander's observations in the Rockies when he states "I have never found a montane grasshopper more than a few hundred feet below its normal altitudinal range but have collected many species up to several thousand feet above normal breeding range." (Alexander 1964). Grasshoppers that occur at high altitudes beyond their normal resident range are termed "accidentals." Accidentals do not complete their cycle in the alpine zone and usually arrive as adults before adults resident at higher altitudes could have matured (Alexander 1964). Of course, even resident alpine species would be "accidentals" on the snow since it is obviously an alien environment to all grasshoppers.

Much more impressive than individual movement is the massive migrations in which some grasshoppers indulge and which would not be limited to marginal ranges. These have been famous since biblical times when "the face of the whole land . . . was darkened" (Exodus 10:15). Perhaps the most notable example of grasshoppers in mountains is on Grasshopper Glacier in northeastern Yellowstone National Park, Montana. Here thousands of grasshoppers are encased in layers or

bands in the ice and are released by melting each summer to be eaten by birds and fish or simply carried away in the water (Gurney 1952). Although some are estimated to have been in the ice 300-400 years, others continue to accumulate. In 1949, for example, numerous individuals of *Melanoplus rugglesi* were found on the snowfield of the glaciers. This species is found primarily in southeastern Oregon and northern Nevada and is assumed to have migrated all that distance (Gurney 1952).

The causes of massive grasshopper migrations are unknown. Possible explanations include: search for food, escape from overcrowding or uncomfortable surroundings, or simply a response to the herding instinct (Hantsbarger 1979). Typically the migration begins by individuals milling about or flying short distances during the hottest time of the day. This excites others and they begin to fly, but still as individuals and in no particular direction. Then, inscrutably, one day the grasshoppers swarm and begin flying enmasse for parts unknown. They now act as a unit and follow the leader without hesitation.

Swarms fly only when conditions are favorable—when it is warm and clear with light wind. Some grasshoppers fly against the wind or diagonally to it, but the migratory grasshopper, *Melanoplus sanguinipes,* rises against the wind and then turns and flies downwind. Rising air currents during the hot time of the day helps the insect gain altitude and flying with the wind increases its travel speed, which is normally about 16 km per hour. The Migratory grasshopper is known to move distances of 40 to 80 km per day and over 800 km in a season (Hantsbarger 1979). The presence of grasshoppers on alpine snow and glaciers is attributed to unstable mountain weather. The swarms apparently land immediately if the sky clouds or if temperatures drop. Therefore, if clouds or storms develop while grasshoppers are passing over the mountains, they quickly drop onto the surface which, if snow, refrigerates them and they die within a few days.

The exact method of grasshopper movement to alpine snow in the Wallowas during 1979 is unknown. Their concentration in one area to the lee of Eagle Cap argues in favor of a single event, e.g., migration, but their limited numbers of only a few hundred favors movement on a lesser scale. There were also no reports of swarming from local ranchers or from spray pilots (personal communication, Ken Goeden, entomologist, Oregon Department of Agriculture). Perhaps the most likely explanation is movement through a series of short sporadic flights by small groups of individuals rather than massive migration. In this regard, the pattern of radiating glacial valleys in the Wallowas may have aided grasshopper movement. These broad and deep valleys provide greater daytime heating, well developed up-valley breezes, and a channeling effect toward Eagle Cap. That grasshoppers can remain active at higher altitudes, and therefore accomplish the trip over several segments, is demonstrated by the vigor of their movements observed under sunny conditions on the snow-free summit of Eagle Cap on July 6. The Wallowas, like the Front Range in Colorado, are very accessible to the surrounding lowlands, being only 20-30 km away, and annual visitation by individual grasshoppers would seem likely to occur, although it has not been documented to my knowledge. Circumstances in 1979 were unusual, however, and resulted in greater numbers of grasshoppers at higher altitudes than normal, especially those on snow.

The grasshoppers are thought to have come primarily from the agricultural areas to the south side of the Wallowas, e.g., the Grande Ronde or Baker Valleys.

This is based on the fact that the wind had been predominantly south-southwesterly for the previous few days. The plateau's weather had been unstable with considerable convection activity. Daytime temperatures reached 30° C on July 3, 4, 5, 6 at both Baker and LaGrande although a trace of precipitation was recorded on each of these days (NOAA 1979). Grasshopper densities in these areas were also above average reaching 40 to 50 per square m (yard) (unpublished survey data, Oregon Department of Agriculture). By contrast, agricultural areas to the north of the Wallowas were sprayed in early July, 1979. The primary pesticide used was malthion which accomplishes almost complete kill within one day and grasshoppers usually do not fly after being sprayed (personal communication, Ken Goeden, entomologist, Oregon Department of Agriculture).

Hatching on the plateau normally occurs from March or April onwards so there is generally ample time for development into adults with full wings by early July. Hatch times are extremely variable, however, depending on altitude and other environmental factors (Handford 1961). For example, hatch times were up to six weeks earlier in the Imhaha Canyon and Baker Valley as opposed to areas around Enterprise on the north side of the Wallowas where grasshoppers were observed still in the nymphal stage on July 4, 1979 (pers. comm., Rick Wescott, entomologist, Oregon Department of Agriculture). This was the same time I was observing full adults on snow in the high Wallowas.

What is the significance of lowland grasshopper movement to higher altitudes? On an ecological basis they serve as food for birds, insects, fish, and other animals. Their presence also provides evidence of processes and events going on in the lowlands which occasionally extend into the mountains. In the Wallowas, this was especially evident in 1979 when the greater grasshopper abundance in the lowlands was expressed by greater numbers in the highlands. The presence of lowland grasshoppers at higher altitudes is reflective of the general trend for insects to move or to be carried bodily upslope in mountains. Such "accidentals" constitute a fringe of pioneers ready to establish the species at the highest altitudes possible for survival in any given season. Daytime temperatures in mountains are high enough for lowland grasshoppers to be active so that eggs and young would be available in most years above where the species normally reaches maturity. Consequently, there is a constant upward pressure for establishment at higher elevations (Alexander 1964).

In addition to providing fresh genetic and ecological opportunities, the movement of organisms across altitudinal gradients demonstrates the essential connectivity of high and low altitudes. While mountains exist as environmental and ecological "islands" amidst surrounding lowland seas, and interchange is limited, it nevertheless occurs. The identification of the pathways and processes involved in this interchange is central to understanding of the mountain ecosystem. The movement of lowland grasshoppers and other arthropods to high elevations is a small, but important, part of that picture.

**Acknowledgments**

Rick Wescott and Kenneth Goeden, Oregon Department of Agriculture, supplied me with unpublished data and answered my many queries. M. A. Brusven, University of Idaho was also most helpful. Lastly, I thank the students of the 1979 geography summer field camp, Portland State University, for their ideas and observations.

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# Radionuclide Transport by Cottontail Rabbits at a Radioactive Waste Disposal Area

## Abstract

A study extending over 21 months was conducted to determine the importance of cottontail rabbits as a radionuclide vector at a solid radioactive waste disposal site in southeastern Idaho. A greater diversity of activation-fission products and significantly ($P \leq 0.05$) greater concentrations of $^{241}Am$ were detected in carcass tissues of cottontails inhabiting the waste disposal area; however, no significant ($P > 0.05$) difference was found for total radionuclide inventories between the waste disposal site (11.2 nCi) and control (13.2 nCi) rabbit populations. Ninety-six and 99 percent of the respective inventories were attributed to $^{90}Sr$ and $^{137}Cs$ activity. Because of the low quantities of radionuclides in rabbit tissues and feces and limited use of the area, cottontail rabbits likely do not transport appreciable quantities of radionuclides to the surrounding environment.

## Introduction

The Idaho National Engineering Laboratory (INEL) of the U.S. Department of Energy is located in southeastern Idaho and used for nuclear research and engineering development. Facilities at the INEL generate low-level radioactive wastes which are disposed at the Radioactive Waste Management Complex (RWMC). The RWMC, established in 1952, is used for disposal of solid activation and fission wastes, and for storage of transuranic wastes mainly from the U.S. Department of Energy Rocky Flats facility in Colorado.

Approximately $8.8 \times 10^6$ Curies (Ci = $3.7 \times 10^{10}$ disintegrations/second) of activation and fission wastes and transuranics have been disposed or stored at the RWMC. Since 1970, transuranic wastes have been stored on an above-ground asphalt pad. Past disposal methods, deterioration of the waste packages, flooding from snowmelt, and soil resuspension have resulted in radioactive contamination of surface and subsurface soils (Harness and Passmore 1976, Card 1977, Markham 1978, Markham *et al.* 1978). Concentrations of radionuclides exceeding background levels have been detected in vegetation samples collected from some areas of the RWMC (Arthur 1982). Above background exposures occur in the RWMC partially as a result of open pits and trenches currently used for disposal of radioactive wastes (Wickham and Janke 1980).

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The mountain cottontail rabbit (*Sylvilagus nuttalli*) is an important prey species on the INEL (Hansen and MacCracken 1978). Since cottontails are mobile, the possibility exists that these animals could transport radioactivity from the RWMC. Therefore, the objectives of this study were to determine the relative abundance and local movements of cottontail rabbits at the RWMC; determine the concentrations of activation, fission, and transuranic radionuclides in cottontail rabbit tissues; and estimate the quantity of radionuclides that could be transported from the RWMC by cottontail rabbits.

#### Study Area

The RWMC occupies 62 ha of the 230,000 ha INEL in southeastern Idaho. The RWMC occurs in a small valley (elevation 1524 m) surrounded by basaltic ridges rising to 18 m above the landscape. Soils vary in thickness from 0 to 7 m and consist of unconsolidated clay, silt, and gravel. Surrounding the RWMC are large tracts of undisturbed areas dominated by big sagebrush (*Artemisia tridentata*), bluebunch wheatgrass (*Agropyron spicatum*), and green rabbitbrush (*Chrysothamnus viscidiflorus*) (McBride *et al.* 1978). Annual precipitation averages 22 cm, with maximum moisture occurring in late spring. Mean temperature is 5.6°C, with recorded extremes of −42°C to 39°C. Mountain ranges to the west and north of the INEL influence local wind patterns causing diurnal southwestern and nocturnal northeastern winds.

Rodent species occurring in or inhabiting the RWMC include 11 small mammal species (Groves 1981) of which the deer mouse (*Peromyscus maniculatus*), Ord's kangaroo rat (*Dipodomys ordii*), and montane vole (*Microtus montanus*) are the most common. Pygmy rabbit (*Sylvilagus idahoensis*), mountain cottontail rabbit, and the black-tailed jackrabbit (*Lepus californicus*) also occur at the RWMC. Commonly occurring game species include mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), sage grouse (*Centrocercus urophasianus*) and mourning doves (*Zenaida macroura*). The most common predator species in the area include the long-tailed weasel (*Mustela frenata*), coyote (*Canis latrans*), rough-legged hawk (*Buteo lagopus*), golden eagle (*Aquila chrysaetos*), and the great horned owl (*Bubo virginianus*).

The RWMC consists of a 36 ha Subsurface Disposal Area (SDA), 22 ha Transuranic Storage Area (TSA), and a 4 ha administrative and operational facility area. Radioactive wastes are segregated according to radiation levels and container type and size, then disposed in pits or trenches. Each filled pit or trench is covered with a minimum 0.6 m of soil and seeded with crested wheatgrass (*Agropyron cristatum*). Invader species, Russian thistle (*Salsola kali*) and summer cypress (*Kochia scoparia*), predominate in areas not seeded with wheatgrass.

The SDA was of most importance to this study because of disposed radioactive waste and radionuclide contamination in surface and subsurface soils. Examination of buried waste indicated some waste containers had deteriorated and were rusted severely or breeched (Card 1977). Low-level transuranic contamination of SDA surface soils occurred during flooding in 1962 and 1969. The greatest concentrations of plutonium were found in soil samples collected in the northeast section of the SDA and in areas northeast (downwind) of the SDA facility (Markham *et al.* 1978).

**Methods and Materials**

Sixty-one trapping areas (12 within SDA and 49 within 500 m of its boundary) were located by direct observation of rabbits, tracks, and fecal deposits. We assumed that cottontail rabbits inhabiting areas greater than 500 m from the SDA boundary were not likely to encounter the waste disposal area (R. Gates, personal communication). The total trapping area included 275 ha of which 36 ha were comprised of the SDA.

Five control rabbits were collected 40 km east of the RWMC on the INEL boundary, an area away from prevailing wind patterns of INEL facilities. An air sampler, operated in the area since 1982, indicates no difference in radioactivity levels between the boundary station and distant (off-INEL) sampler stations (U.S. DOE 1983).

Rabbits were captured by positioning a 23 x 23 x 81 cm steel-wire live trap near burrow entrances, culverts, or areas exhibiting rabbit activity. Trapping was conducted during January-February, May-June, and September-October with approximately 4 days trapping effort conducted at each location per seasonal period. All captured rabbits were ear-marked with either a metal fingerling tag or two 1.3 cm diameter green plastic discs. The location of each captured rabbit was plotted on a 2075:1 scale color aerial photograph of the SDA and surrounding area. Habitat type at each capture location was categorized as native sagebrush, disturbed areas (culverts, buildings, storage containers), or reseeded grasslands.

Notes were taken 3 days each week on the number of cottontail rabbits residing in or near the SDA. Rabbits observed by culverts immediately adjacent to the SDA fenceline were counted as an SDA inhabitant. The occurrence of cottontail rabbit feces on pellet plots was recorded within the SDA (87 plots) and surrounding area (203 plots). Each pellet plot (2 m in diameter) was initially examined in June 1978, cleared, then reexamined in May of the following year. Small feces were discounted from the pellet plots to discriminate from any contribution of pygmy rabbits. Also, jackrabbit populations were low during the study period (Stoddart 1983), and it was assumed that their feces contribution was minimal.

Fifteen cottontail rabbits were sacrificed for radionuclide analysis, 10 from the SDA and five from the control area. The hide and remaining carcass were sampled, weighed, dried at 80°C for 5 days, then reweighed. Instruments were cleaned between each sample dissection to assure no cross-contamination. Tissues were analyzed for gamma-emitting radionuclides on a lithium-drifted germanium crystal detector coupled to a computerized multichannel analyzer. Counting time for each sample analysis was 60 minutes. Minimum detectable concentrations (pCi/g dry weight) for gamma-emitting radionuclides in rabbit tissues were 0.2 ($^{60}$Co), 0.1 ($^{95}$Nb), 1.0 ($^{106}$Ru), 0.02 ($^{137}$Cs), and 1.1 ($^{144}$Ce).

Transuranic radionuclide analyses were limited to those nuclides prevalent in waste disposed at the SDA prior to 1970, specifically $^{238}$Pu, $^{239,240}$Pu, and $^{241}$Am (U.S. DOE 1979). Carcass and hide samples were sent to a commercial laboratory for $^{90}$Sr and transuranic analysis (Wessman *et al.* 1971). Tissues were oven-dried prior to analysis; therefore, data were adjusted to wet tissue radionuclide concentrations using correction factors of 72 percent for lung, GI tract, and carcass, and 54 percent for hide. Minimum detectable concentrations (pCi/g dry weight) for those radionuclides in rabbit tissues were 0.009 ($^{90}$Sr) and 0.0004 ($^{238}$Pu, $^{239,240}$Pu, and $^{241}$Am). A student t-test was used to determine whether radionuclide concentrations in SDA cottontail rabbit were significantly different from control samples.

Total radionuclide concentrations in SDA and control area rabbits were estimated using a mean weight of 616 g obtained from 128 live-trapped rabbits. Data were obtained on the mean percentage wet weight of hide (13 percent) and remaining carcass (87 percent) from dissection of the 10 SDA and 5 control rabbits. Mean radionuclide concentrations (pCi/g) in each tissue group were multiplied by the tissue weight, then summed to give the whole body concentration of each radionuclide. Those summations were multiplied by the estimated number of rabbits occurring at the SDA and control area to obtain an overall inventory of radionuclides in rabbits.

#### Results

Between January 1978 and September 1979, 3,725 trap nights were conducted to live-trap 128 cottontail rabbits in and adjacent to the SDA, a capture ratio of 1/14.9 trap nights. Thirty-eight cottontail rabbits were trapped within the SDA, usually in culverts or beneath buildings and storage containers. Ninety cottontail rabbits were trapped outside the SDA: 58 in undisturbed sagebrush; 26 in disturbed areas of the TSA, the service facility area, and a monitoring well building; and 6 within crested wheatgrass stands. Cottontail rabbit fecal occurrence on pellet plots indicated that only 22 percent of the SDA plots contained rabbit feces compared with 65 percent in the sagebrush areas.

Approximately 42 percent of the cottontail rabbits (56 animals) were recaptured, of which one-half were recaptured at their initial capture station. Based on linear movements between successive captures, the mean movement distance for cottontail rabbits was 90 m. Maximum distance of linear movement for an individual rabbit was 839 m. The rabbits exhibited a large variability in movement pattern and did not appear restricted by habitat type.

Radionuclides detected in SDA rabbits included $^{51}$Cr, $^{54}$Mn, $^{57}$Co, $^{60}$Co, $^{90}$Sr, $^{134}$Cs, $^{137}$Cs, and $^{140}$Ba. Cobalt-60, $^{90}$Sr, and $^{137}$Cs were detected in control rabbits. With the exception of $^{90}$Sr and $^{137}$Cs, most of the above radionuclides were detected in only one sample. Strontium-90 and $^{137}$Cs were frequently detected in rabbits from both the SDA and control area (Table 1); concentrations of the radionuclides in carcass and hide samples indicated no significant ($P > 0.05$) differences between the rabbit groups. Other gamma-emitting radionuclides detected in rabbit tissues occur naturally ($^{7}$Be, $^{40}$K, $^{208}$Tl, $^{212}$Pb, $^{214}$Pb, and $^{214}$Bi) in the environment; therefore, no statistical analyses were conducted for those radionuclides.

Transuranic radionuclides were detected in rabbits from both the SDA and control area (Table 1). No significant ($P > 0.05$) differences were observed between SDA and control area concentrations of $^{238}$Pu or $^{239,240}$Pu in carcass or hide samples. Americium-241 concentrations in SDA rabbit carcass samples (0.01 pCi/g) were significantly ($P < 0.05$) greater than in the control area rabbit carcasses (0.001 pCi/g). No significant difference was observed between the SDA and control area concentrations of $^{241}$Am in hide samples.

The total inventory of $^{90}$Sr, $^{137}$Cs, $^{238}$Pu, $^{239,240}$Pu, and $^{241}$Am in hide and carcass were not significantly different between animals inhabiting the SDA and control areas, even though $^{241}$Am concentrations in rabbits inhabiting the SDA were 10 times greater than that in control area rabbits (Table 2). No significant differences were observed for whole body inventories of $^{90}$Sr, $^{137}$Cs, $^{238}$Pu, $^{239,240}$Pu, and $^{241}$Am

TABLE 1. Mean (X ± SD) radionuclide concentrations (pCi/g wet weight) in cottontail rabbit hide and carcass tissues collected at the Subsurface Disposal Area (SDA) and control area in southeastern Idaho.

| | | Radionuclide | | | | |
|---|---|---|---|---|---|---|
| Tissue | | $^{90}Sr$ | $^{137}Cs$ | $^{238}Pu$ | $^{239,240}Pu$ | $^{241}Am$ |
| | SDA | | | | | |
| Hide | X ± SD | 0.43 ± 0.18 | 0.18 ± 0.15 | 0.002 ± 0.001 | 0.009 ± 0.010 | 0.029 ± 0.046 |
| | Range | 0.23 – 0.75 | MDC[a] – 0.44 | MDC – 0.007 | 0.0005 – 0.036 | 0.0007 – 0.157 |
| | n | 10 | 10 | 10 | 10 | 10 |
| ,, | CONTROL | | | | | |
| | X ± SD | 0.44 ± 0.15 | 0.31 ± 0.07 | 0.003 ± 0.003 | 0.002 ± 0.001 | 0.002 ± 0.001 |
| | Range | 0.32 – 0.66 | 0.22 – 0.38 | 0.0006 – 0.008 | 0.002 – 0.003 | 0.0007 – 0.003 |
| | n | 4 | 5 | 4 | 4 | 4 |
| Carcass | SDA | | | | | |
| | X ± SD | 0.30 ± 0.24 | 0.14 ± 0.33 | 0.001 ± 0.0004 | 0.004 ± 0.003 | 0.010 ± 0.009[b] |
| | Range | MDC – 0.73 | MDC – 1.06 | MDC – 0.001 | 0.001 – 0.008 | 0.001 – 0.029 |
| | n | 10 | 10 | 10 | 10 | 10 |
| ,, | CONTROL | | | | | |
| | X ± SD | 0.37 ± 0.09 | 0.16 ± 0.12 | 0.001 ± 0.001 | 0.002 ± 0.001 | 0.001 ± 0.001 |
| | Range | 0.30 – 0.49 | MDC – 0.28 | MDC – 0.002 | 0.0008 – 0.003 | MDC – 0.002 |
| | n | 4 | 5 | 4 | 4 | 4 |

[a] Less than the minimum detectable concentration.

[b] Significant ($P \leq 0.05$) difference between SDA and control area radionuclide concentrations in tissues.

TABLE 2. Total radionuclide inventory (pCi) in selected tissues and whole body of an average cottontail rabbit (616 g) inhabiting the SDA and control area in southeastern Idaho.

| | | Radionuclide | | | | | |
|---|---|---|---|---|---|---|---|
| Location | Tissue | $^{90}Sr$ | $^{137}Cs$ | $^{238}Pu$ | $^{239,240}Pu$ | $^{241}Am$ | Total |
| SDA | Carcass | 160.6 | 75.0 | 0.54 | 2.14 | 5.35 | |
| | Hide | 34.4 | 14.4 | 0.16 | 0.72 | 2.3 | |
| | Whole Body | 195.0 | 89.4 | 0.7 | 2.9 | 7.7 | 295.7 |
| Control | Carcass | 198.2 | 85.6 | 0.54 | 1.07 | 0.54 | |
| | Hide | 35.2 | 24.8 | 0.24 | 0.16 | 0.16 | |
| | Whole Body | 233.4 | 110.4 | 0.8 | 1.2 | 0.7 | 346.5 |

between SDA (296 pCi) and control area (347 pCi) rabbits. Ninety-six percent of the SDA rabbit radionuclide body burden and 99 percent of the control rabbit radionuclide body burden were comprised of $^{90}Sr$ and $^{137}Cs$. By multiplying the total radionuclide body burden presented in Table 2 by the 38 rabbits trapped in the SDA between January 1978 and September 1979, a total inventory of 11.2 nCi radioactivity ($^{90}Sr$, $^{137}Cs$, $^{238}Pu$, $^{239,240}Pu$, and $^{241}Am$) occurred in those rabbits. In order to make a uniform comparison between SDA and control rabbits, it was assumed the control area had an equal number of rabbits. Therefore, a total of 13.2 nCi activity would have occurred in control rabbits.

#### Discussion

Cottontail rabbits were trapped in both the disturbed areas of the SDA and sagebrush habitat adjacent to the facility. All rabbits captured in the SDA were trapped in culverts or beneath storage and waste containers. Since no rabbit burrows were located in the SDA, it is doubtful that cottontail rabbits directly contacted disposed waste; however, on a few occasions rabbits were observed in open pits and trenches used for waste disposal. Previous research in Wisconsin concluded that cottontail rabbits used woodpiles and junkpiles as daytime resting locations (Trent and Rongstad 1974).

Eighty-four percent of the rabbits trapped at the SDA (N = 38) were trapped in culverts at the boundary; therefore, it is probable that some of those rabbits were not permanent residents of the SDA. The implications are that cottontail rabbits use the culverts for shelter and, based on the lower occurrence of feces in the SDA, more readily utilize sagebrush areas elsewhere. Notwithstanding, the radionuclide inventories projected in the paper were based on the 38 rabbits trapped at the SDA.

No significant difference was determined for $^{90}Sr$ and $^{137}Cs$ concentrations in SDA versus control area cottontail rabbits; however, transuranic radionuclide analyses indicated that SDA rabbit carcass tissues contained a statistically greater concentration of $^{241}Am$ than control rabbits. The total average body burden of $^{241}Am$ was less than 2 percent of the total average radionuclide burden occurring in SDA cottontail rabbits (Table 2). The source of $^{241}Am$ in SDA rabbit tissues was likely due to ingestion of soil and vegetation since above background concentrations of $^{241}Am$ have been detected in SDA soil and vegetation (Markham *et al.* 1978, Arthur 1982).

One radionuclide transport mechanism not examined in this study was cottontail rabbit defecations in the SDA and surrounding sagebrush. Rabbits ingesting vegetation and soil in the SDA could transport radioactivity outside of the facility. This type of transport mechanism has been documented for jackrabbits at the Hanford Reservation in Washington (O'Farrell and Gilbert 1975). The jackrabbits fed in radioactive contaminated areas and transported and eliminated contamination to areas surrounding the radioactive waste disposal trenches. Fecal elimination may be an important transport vector for transuranic radionuclides since minimal quantities of these radionuclides would be expected to be assimilated by body tissues.

The overall quantity of radionuclides transported by rabbits inhabiting the Subsurface Disposal Area in southeastern Idaho (11.2 nCi) is smaller than estimated inventory quantities of 66 $\mu$Ci/yr for small mammal burrowing (Arthur and

Markham 1983), 77 μCi/yr for vegetation (Arthur 1982), and 7.2 μCi/yr for coyotes (Arthur and Markham 1982). Due to these low inventories of radioactivity and the low use of the SDA by cottontails, the role of this species as a mode of radionuclide transport will not likely result in the addition of appreciable quantities of radionuclides in the environment surrounding the SDA.

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# Shiner Perch and Pacific Staghorn Sculpins in Yaquina Estuary, Oregon

**Abstract**

The shiner perch (*Cymatogaster aggregata*) and Pacific staghorn sculpin (*Leptocottus armatus*) were intertidally seined at an embayment at Yaquina Estuary, Oregon from August 1975 through July 1976. The shiner perch was most common from June through October, but the catch of this fish declined after August. Young shiners were born from June through mid-August. Most shiners caught were less than 9 cm TL.

The Pacific staghorn sculpin was present during every month. Young-of-the-year first appeared in December, and staghorns less than 2 cm TL were collected through April. Most staghorns were less than 12 cm Tl. The preopercular spines of staghorns do not appear to be an effective defense against Great Blue Herons (*Ardea herodias*), which swallowed the staghorns without first breaking off the spines.

## Introduction

The shiner perch (*Cymatogaster aggregata*) and the Pacific staghorn sculpin (*Leptocottus armatus*) are among the most numerous fish species collected in bays and estuaries in Oregon (Beardsley 1969, Hostick 1975, Stout 1976, Durkin *et al.* 1977, Bottom and Forsberg 1978, Hutchinson 1979, Mullen 1979, Myers 1980, Bayer 1981), Washington (Anderson and Chew 1972, Cross *et al.* 1979, Fresh 1979), and California (Anderson and Bryan 1970, Fierstine *et al.* 1973, Allen and Horn 1975). These species have also been frequently studied in California (e.g., Jones 1962, Anderson and Bryan 1970, Bane and Robinson 1970, Shaw *et al.* 1974, Odenweiler 1975, Tasto 1975, Eckmayer 1979, Darling *et al.* 1980), Washington (Suomela 1931, Weiss 1969), and British Columbia (Gordon 1965, Weibe 1968). However, information concerning the natural history of these species in Oregon, except Wilson and Milleman (1969), is either unpublished or in governmental publications of limited distribution. The objective of this paper is to outline aspects of the life history of the shiner perch (henceforth termed shiner) and the Pacific staghorn sculpin (henceforth termed staghorn) in Yaquina Estuary, Oregon and to compare these aspects for shiners and staghorns at other Oregon estuaries.

## Study Area and Methods

The shiner perch and staghorn sculpin were collected at study sites shown in Bayer (1981) at the 15.8 km² Yaquina Estuary (44°38'N, 124°03'W), a drowned river valley located on the mid-Oregon coast. A beach seine 3.0 m long and 1.1 m high with a 10 mm stretched mesh was used to capture fish in the upper intertidal (+0.9 to +1.3 m above MLLW) on mudflats, and a specially designed seine of the same dimensions (Bayer 1979) was used to capture fish in the lower intertidal (−0.2 to +0.4 m above MLLW) in a persistent eelgrass bed (Bayer 1980).

In August 1975, and from December 1975 through July 1976, five samples were taken each month in the lower intertidal during daylight hours. Five monthly daylight collections were also made in the upper intertidal in August 1975 and from October 1975 through July 1976. Collecting during the night was carried out in August 1975 (five times in both the upper and lower intertidal), September and December 1975 (four times each month in the lower intertidal), October 1975 (two samples in the lower intertidal), and November 1975 (one sample in the lower intertidal). Each sample was obtained from a series of 10 hauls, each about 30 m long. Seining velocity was about 0.5 m/s in water 0.4-0.7 m deep. At upper intertidal elevations, the seine was pulled to shore at the end of a haul, but the amount of macrophyton caught in the net in eelgrass sometimes made it necessary to terminate seining in water. When a haul was terminated in water, the foot line of the net was raised as rapidly as possible until it was level with the head line, and the seine was carried to shore. The area covered in a sample was about 600 $m^2$.

Generally, the total length (TL) and wet weight of each fish were measured. Exceptions were made for shiners less than 9 cm in August through October 1975 and July 1976 and for staghorns less than 4 cm from January through May 1976; these fish were all counted and the total lengths and wet weights of a sample of at least 100 fish were measured each month.

I also collected shiners and staghorns dropped by Great Blue Herons (*Ardea herodias*) at the heron's nesting colony near Yaquina Estuary during the summers of 1973-1980. The total lengths of most of these fish were measured.

Coefficients of Variation (CV) were calculated as a percentage by dividing the standard deviation (SD) by the mean and multiplying by 100. To convert the average number of shiners/sample caught during darkness in the lower intertidal from September through November 1975 to daylight values, I multiplied the September-November means by a conversion factor, which was the average number of shiners/sample in the lower intertidal in August during daylight divided by the average number of shiners/sample in the lower intertidal in August in darkness. All length measurements are total length (TL) unless specifically noted as standard length (SL).

#### Results and Discussion

Shiner Perch

Although approximately equal seining efforts were made in the upper intertidal as were made in eelgrass, 95 percent of the 22,171 shiners collected were in eelgrass. Further, significantly more shiners were caught during darkness than during daylight in either the upper or lower intertidal (Bayer 1981) with a density at night in August 1975 as great as 5.8 fish/$m^2$ ($\bar{x} = 2.3$, $N = 5$ samples) and a maximum standing stock of 11.4 g/wet weight $m^2$ ($\bar{x} = 4.6$ g/$m^2$).

Shiners were absent in January and February and were most common from June through October (Figure 1), but calculations from Myers (1980: Appendix Table 1) indicated that Yaquina shiners in 1978 were abundant from May through October with a peak abundance for all her sites combined in 1977 in August and in 1978 in July. After August, catches declined markedly in 1975 for daylight corrected means in eelgrass (Figure 1) and also for night catches in eelgrass from August through October; Myers (1980) likewise seined fewer shiners after August in 1977

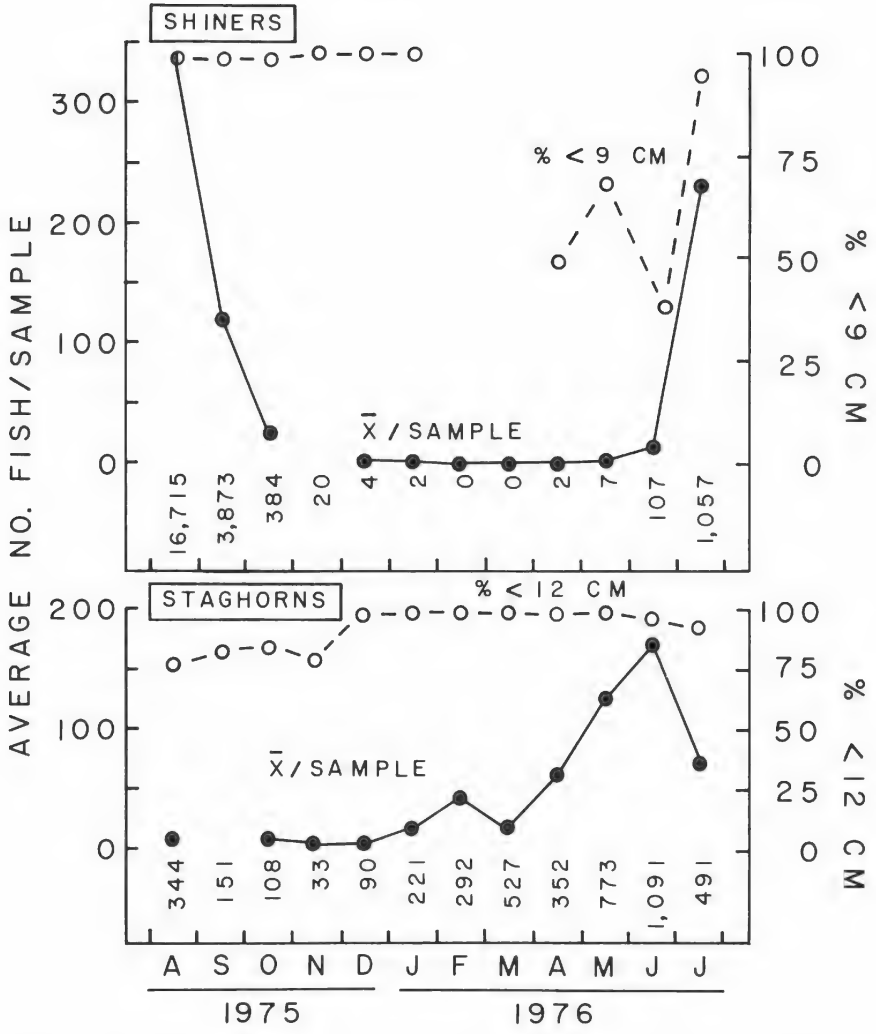


Figure 1. The relative size of fish caught/month, the average number of shiners/sample collected during daylight (or converted to daylight values for September-November, see Methods) in the lower intertidal, and the average number of staghorns/sample seined during daylight in the upper intertidal. The total numbers of shiners or staghorns caught each month irregardless of tidal height or light conditions are along the baseline.

and 1978. Elsewhere in Oregon, shiners were abundant from May through October with a peak in July at Youngs Bay (Higley and Holton 1975), from May through November at Tillamook Bay (Bottom and Forsberg 1978), and from June through October at the Salmon River (Mullen 1979). In Washington, shiners were common from June through November (Anderson and Chew 1972).

Large shiners (i.e., ≥9 cm and ≥8 g) were collected between April and October but were only common between June and October (Figure 2). In June, 10 cm or longer shiners first appeared. There may be some yearly variation at the Yaquina, however, as Myers (1980) found 12 cm SL or longer shiners from March through October 1978, and I found an 11 cm shiner caught by a Great Blue Heron in late April 1980. At Youngs Bay, a 14 cm shiner was seined on 8 May 1974 (Higley and Holton 1975), and at Tillamook Bay, Bottom and Forsberg (1979) reported that most adults of unspecified size arrived in May and left by September.

The first young-of-the-year shiners were seined on 17 June 1976, and they ranged from 4.2-4.9 cm. Shiner young at Yaquina Estuary range from 3.9-4.9 cm at parturition (Wilson and Milleman 1969), and some were seined that had grown to 5.1 cm by 2 July 1976 and to 5.9 cm by 15 July 1976. Thus, the birth of shiners at the Yaquina seems to begin in June each year, as evidenced from the young shiners (5.0 cm on 1 July 1973, 4.0 cm on 26 June 1975, 5.8 cm on 6 July 1977, and 5.3 cm on 9 July 1978) I found captured by Great Blue Herons. In addition, Myers (1980) found young in June 1978 at the Yaquina. Elsewhere in Oregon, McConnaughey (1971) at Coos Estuary and Hutchinson (1979) at Siuslaw Estuary also found young first appearing in June, but Durkin *et al.* (1977) at the Columbia River and Bottom and Forsberg (1978) at Tillamook Bay did not find young until July. Thus, the commencement of the birth of Oregon shiners is more similar to the usual June or July onset at British Columbia (Wiebe 1968) and Puget Sound (Anderson and Chew 1972) than for the March-May onset in southern California (Bane and Robinson 1970, Fierstine *et al.* 1973, Odenweiler 1975).

As shiners less than 5 cm were seined from June through August, young shiners at the Yaquina appear to be born from June through August. In 1975, however, most shiners appeared to have been born by August 15, as by that date only 6 percent of the young (N = 242) were less than 5 cm. Similarly, Myers' (1980) data indicate that she collected young shiners less than 5 cm TL only through August 1977 and through July 1978, if her SL data are converted to TL measurements using Wilson and Milleman's (1969), Anderson and Bryan's (1970), Odenweiler's (1975), or Eckmayer's (1979) equations. Thus, there appears to be little yearly variation in the duration of parturition at the Yaquina.

Most (95 percent) shiners were less than 5 g, and most (≥95 percent) were less than 9 cm (and about 8 g) except in the April-June period (Figure 1). Because shiners are about 8.7 cm at the end of one year (calculated from Odenweiler 1975 and Eckmayer 1979), most Yaquina shiner perch are a year old or less during periods when they are abundant (Figure 1). Shiners ranged from 4.0-15.0 cm and from less than 0.5 g to 49.1 g, and Great Blue Herons caught shiners ranging from 4.0-15.2 cm (N = 794). Shiner weights increased exponentially with length (Figure 3). However, shiner weights for each 1 cm class varied markedly (i.e., CV's for each cm class were about 15 percent for shiners over 7 cm) with overlap in weights between classes (Figure 3). The predicted length-weight equation (calculated for fish 15 cm or less) best predicted average weights for each length class for fish under 14 cm (Figure 3). Separate length-weight relationships for male and female shiners at the Yaquina were not determined, although separate relationships for males and females were computed for California shiners (Anderson and Bryan 1970, Eckmayer 1979).

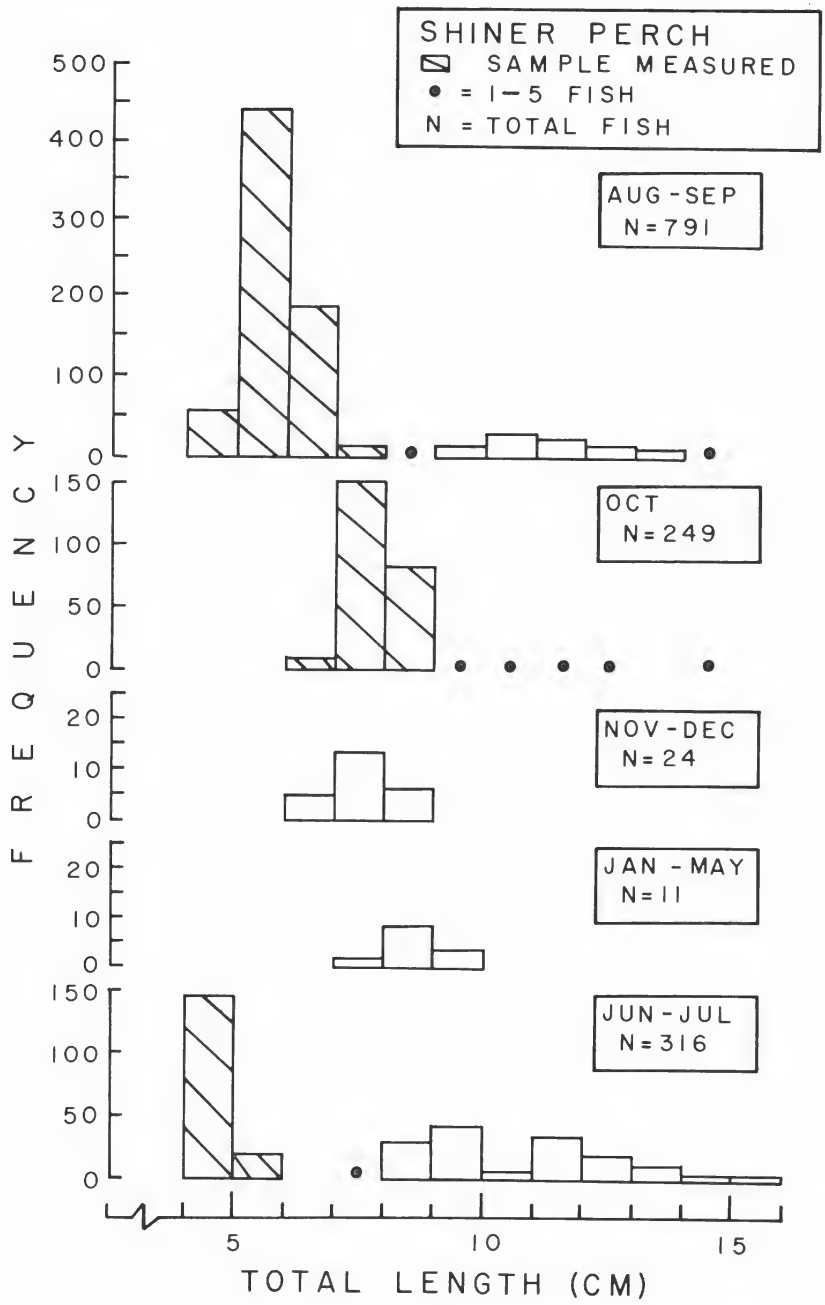


Figure 2. Length-frequency for shiner perch. "Sample measured" signifies that only a portion of fish less than 8 or 9 cm were measured.

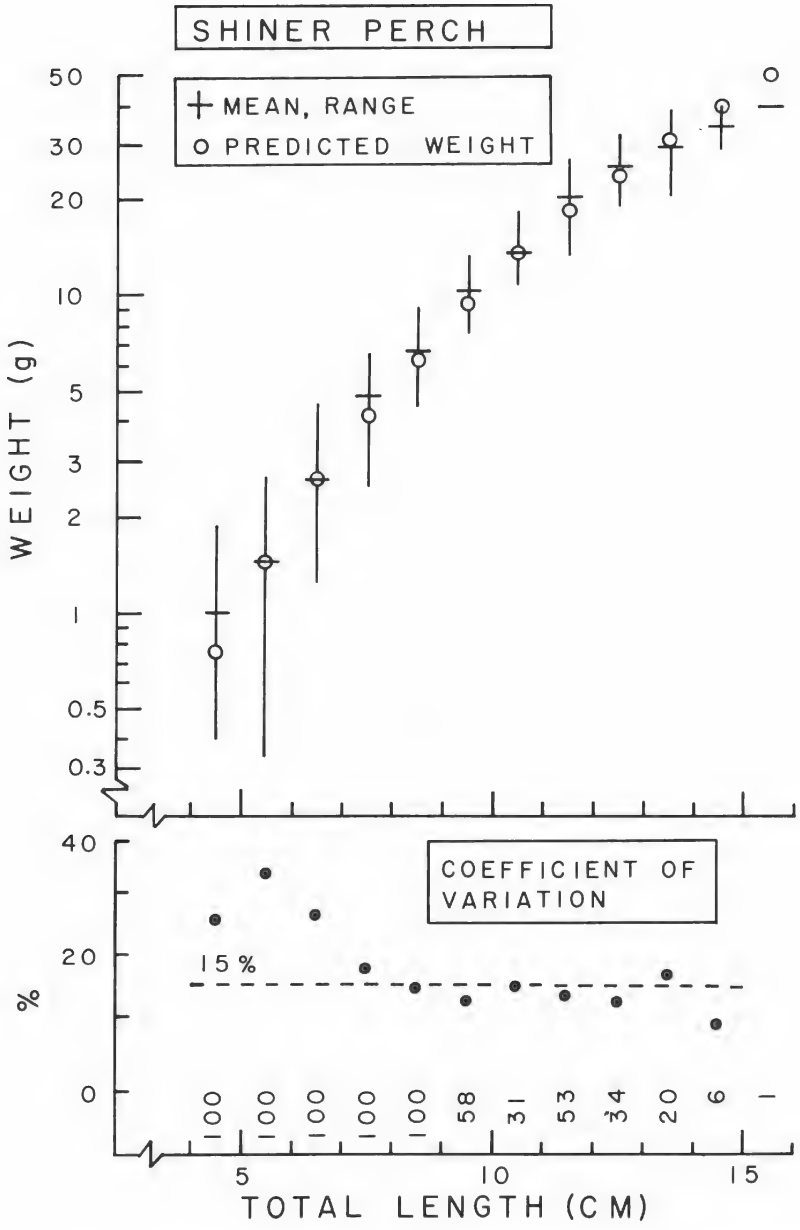


Figure 3. Length-weight relationships for shiner perch. Coefficents of Variation (CV), means, and ranges are for 1 cm intervals with sample sizes along the baseline. The length-weight equation was calculated from the measurements of 45 shiners with 4 fish for each cm class, except there was only one shiner for the 15.0-15.9 cm class. Predicted values were determined from mid-interval lengths from the length-weight equation ($W = 4.07 \times 10^{-3} TL^{3.45}$, $r = 0.99$).

Most (69 percent) of the 4,473 staghorns seined were in the upper intertidal (Bayer 1981). The number of staghorns collected in darkness did not differ significantly from the number collected during daylight in either eelgrass or the upper intertidal (Bayer 1981).

Staghorns were present each month but were most common from February through July 1976 with the peak abundance in June (Figure 1). Similarly, staghorns were present monthly in other studies at Yaquina Estuary (Beardsley 1969, Burreson 1973, Myers 1980). Calculations from a combination of all Myers' (1980, Appendix Table 1) sites indicate that staghorns at the Yaquina in 1978 were most common from February through August with a peak in June. At Tillamook Bay, staghorns were most common from March through October (Bottom and Forsberg 1978).

Small (1.8-2.0 cm) staghorns were first captured in December and were seined through April. Staghorns less than 3 cm were found from December through July, (Figure 4). Likewise, Myers (1980) only found staghorns less than 2 cm SL at the Yaquina from December through February 1978 and in April 1978, and Bottom and Forsberg (1978) first found juvenile staghorns at Tillamook Bay in December.

Length-frequency data indicate that staghorns may grow to about 11-14 cm by the end of one year (Figure 4). This agrees with Jones' (1962), Burreson's (1973), and Tasto's (1975) length-frequency data, but not with the length-frequency data of Weiss (1969). Since staghorns spawn during about a 5-6 month period (Jones 1962) with larvae present at the Yaquina from August through March (Pearcy and Myers 1980), the multiple length-frequency modes for Weiss' staghorns less than 12 cm may indicate multiple peaks in spawning or hatching rather than different year classes as suggested by Weiss (1969). Weiss (1969) also used otoliths to determine several year classes for staghorns less than 12 cm, but Jones' (1962) measurements of otoliths indicated that staghorns were about 11-13 cm when they were one year old.

Most (63 percent) of the 4,473 staghorns weighed less than 5 g; however, staghorns weighing over 5 g represented 86 percent of the total staghorn biomass seined (31.9 kg). Staghorns ranged from 1.8-27.0 cm and less than 0.1 g to a 25.3 cm staghorn weighing 273.4 g. As in California estuaries and bays (Jones 1962, Tasto 1975), most ($\geq$75 percent, Figure 1) staghorns were small (i.e., $<$12 cm) and probably less than one year old. Staghorn weights increased exponentially with length (Figure 5), but there was much variation in weights for each cm class with CV's of 20-38 percent for each class of staghorns less than 9 cm and about 10-22 percent for staghorns over 9 cm (Figure 5). Predicted weights for mid-interval lengths closely matched average weights for each cm class of staghorns from 3-26 cm (Figure 5).

Staghorns have large upper preopercular spines on both sides of the head; when a staghorn is caught the fish raises these spines. Tasto (1975) and Forbes (1983) indicated that these spines may be useful for defense; however, the spines do not appear to deter at least one avian predator, the Great Blue Heron. I examined 472 staghorns, ranging from 3.3-24.3 cm, that were captured, swallowed, and later regurgitated by these herons. In none of these staghorns was either preopercular spine broken, and for some staghorns 12 cm or less both spines were still raised

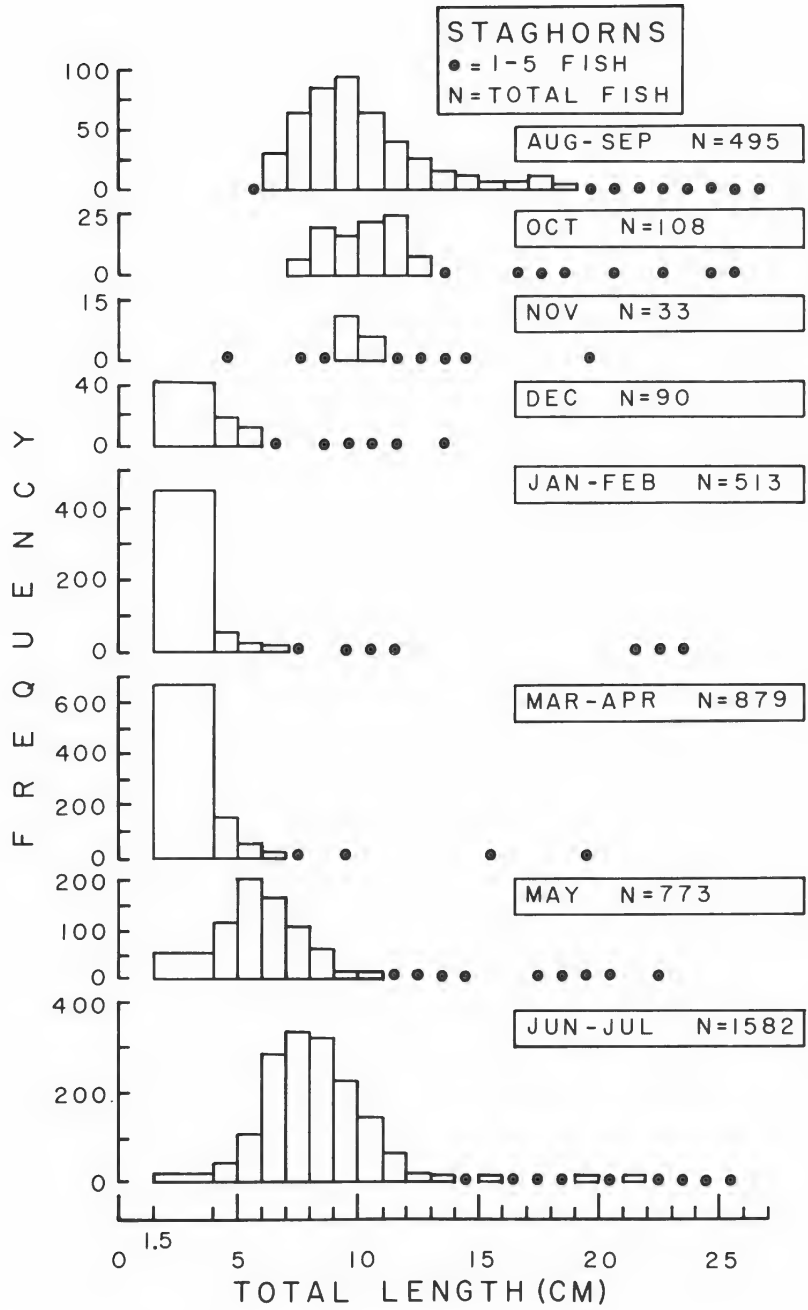


Figure 4. Length-frequency for staghorns.

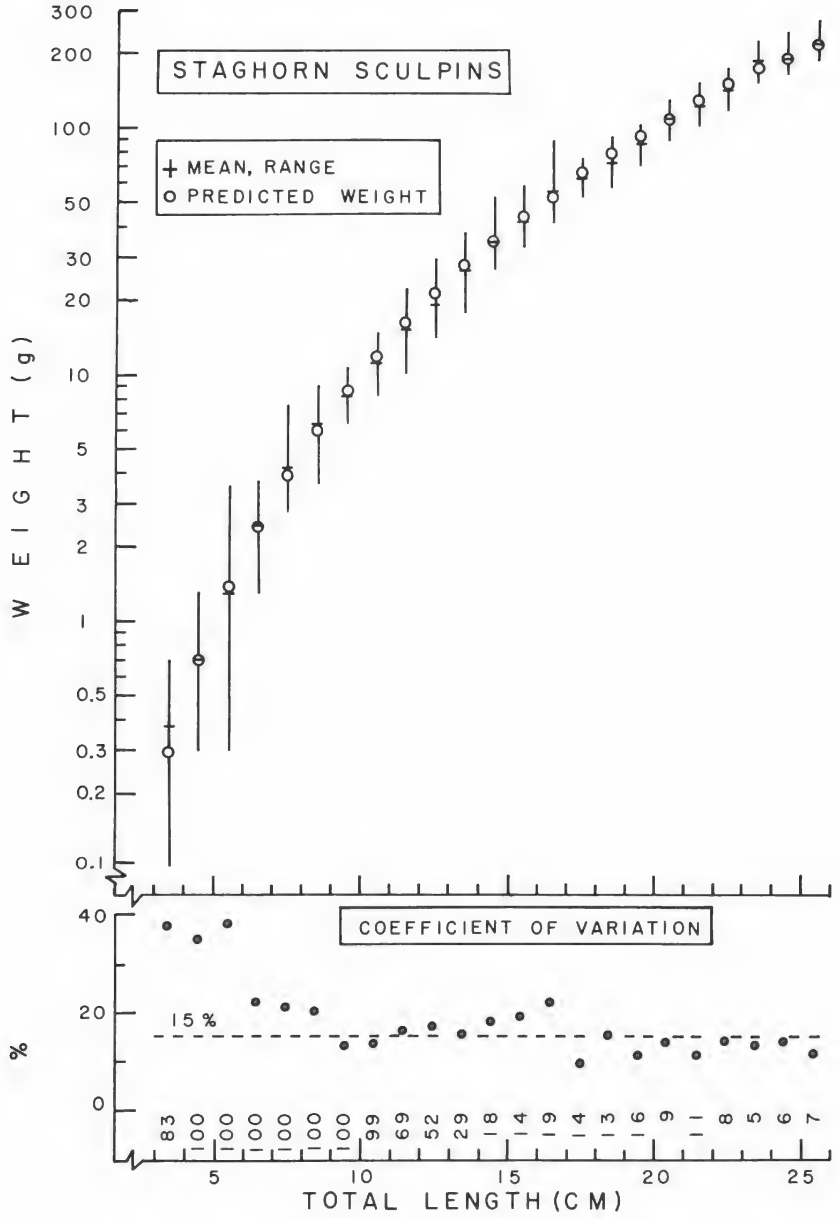


Figure 5. Length-weight relationships for staghorns. Coefficients of Variation (CV), means, and ranges are for 1 cm intervals with sample sizes along the baseline. The length-weight equation was calculated from the measurements of 137 staghorns with 6 fish for each cm interval, except there were 5 fish for the 23.0-23.9 cm interval. Predicted values were determined for mid-interval lengths from the length-weight equation ($W = 5.14 \times 10^{-3} TL^{3.31}$, $r = 0.99$).

after herons had regurgitated them to feed their young. Additionally, I observed these herons capture several hundred staghorns without a single staghorn escaping once the heron picked it up and held it long enough (i.e., about 5 s) for me to identify it as a staghorn.

Several studies (Kendall 1966, Tasto 1975) have indicated that staghorns follow the tide. This resulted in staghorns sometimes being stranded on intertidal mudflats at low tide (personal observation). Staghorns have been observed to bury themselves in aquaria (Tasto 1975), but I also found a 17.5 cm staghorn buried in mud under a clam shell in an intertidal mudflat at the Yaquina. After such a stranding, a staghorn is vulnerable to avian predation. I observed Great Blue Herons capture and eat several approximately 12-15 cm staghorns that were shallowly buried in intertidal mudflats of the Yaquina.

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## Review of *Ethnobotany of the Nitinaht Indians of Vancouver Island*[1]

by Nancy J. Turner, John Thomas, Barry F. Carlson, and Robert T. Ogilvie.
Occasional Papers of the British Columbia Provincial Museum, No. 24, pp. i-x, 1-165.
British Columbia Provincial Museum and Parks Canada, Victoria, B.C. (1983).

This is the most recent in a series of ethnobotanical studies of British Columbia Indians published by Turner and her colleagues. As we have come to expect, it is an excellent piece of work, comprehensive, well documented, and clearly presented. It exhibits the Turner trademark: a rich synthesis of ethnohistoric, ethnographic, and linguistic detail with botanical science, amply illustrated. Turner's research since 1972 has documented the extant ethnobotanical knowledge of other Vancouver Island Native peoples such as the Nootka, Southern Kwakiutl, and Coast Salish, other coastal Indian groups such as the Haida and Bella Coola, as well as interior peoples such as the Lillooet, Thompson, and Okanagan-Colville (published in *Economic Botany* and the British Columbia Provincial Museum's journal, *Syesis*, or as occasional papers of the latter). Popular summaries are available as B. C. P. M. handbooks.

In the present volume she shares authorship with John Thomas, a 72-year-old Nitinaht elder, Barry Carlson, a linguist deeply involved with British Columbia Indian language teaching programs, and Robert Ogilvie. This is indicative of her fruitful collaboration with other scholars, Indian and non-Indian. The monograph includes a brief introduction to the project, the Nitinaht people (residents of the southwestern coast of Vancouver Island), and the local environment (this a rather tedious catalog of habitat types and indicator species). There follows a summary discussion of plant uses as food (32+ species), in technology (50+ species), and medicine (30-40 species). Though estimates of quantities involved in the traditional diet have not been attempted, it is clear that plant foods (the primary dietary contribution of women as food producers) were essential and highly valued despite the abundance of fish and other marine animal foods available. Furthermore, cooperation in the harvest, preparation, and consumption of plant foods is described as an important feature of their use, contrary to the stereotype of women's economic contribution as lacking social import.

The discussion of nomenclature and classification that concludes this section is of particular interest to students of the history of biological systematics. The Nitinaht botanical taxonomy is like other hunter-gatherer systems in its very limited use of binominal names—thus virtually all taxa are what Berlin calls "folk generics." (*Ann. Rev. Eco. Sys.* 4:259-271, 1973). Also Nitinaht well illustrates the ambiguities involved in defining a set of mutually exclusive "life-form" taxa. The role of cultural utility in folk sytematics is illustrated by the nomenclatural discrimination between two forms of wild clover (*Trifolium wormskioldii*), a primary "root" food, where botanical sytematists fail to perceive a significant pattern of variation.

The bulk of the monograph is taken up by an annotated list of the more than 130 species of plants (including some 30-odd introduced species) named and used by speakers of this Native language, including algae, lichens, fungi, and bryophytes, as well as the vascular flora. This section is best browsed over a period of time. Summaries of the cultural role of such key species as bull kelp, western red cedar, salal, wild clover,

[1]Available from the British Columbia Provincial Museum, Victoria, B.C., Canada V8V 1X4 for $5 Canadian.

Pacific cinquefoil, and stinging nettle may run to several pages. Six appendices discuss 1) unidentified native plant categories, 2) unrecognized local plants (a useful corrective for those who assume that Indian peoples knew *everything* worth knowing about their local environment), 3) a dictionary of native terminology descriptive of plants and their products, 4) an inventory of introduced plants (noting intriguing nomenclatural innovations, e.g., figs are called 'looks like a camas bulb'), 5) a table of Nitinaht speech sounds, and 6) a text in the Nitinaht language (with interlinear English translation) describing the harvest and preparation of "root" foods.

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# Current Geographic Distribution and Abundance of Columbian White-Tailed Deer, *Odocoileus Virginianus Leucurus* (Douglas)

**Abstract**

The current distribution of Columbian white-tailed deer (CWTD), *Odocoileus virginianus leucurus* (Douglas), is limited to remnant populations along the lower Columbia River and in Douglas County in southwestern Oregon. Distribution of CWTD in southwestern Oregon encompassed 1199 km² (463 mi²), about 25 percent of the historical range in Douglas County. This population occurred within predominantly *Quercus* woodland communities. Densities varied from 1.4 per km² along the periphery of the range to 35.2 per km²; the entire population totaled about 3000. Within the center of the range, CWTD densities were positively correlated with percent woodland cover; the highest densities occurred within areas supporting at least 50 percent cover.

Five sub-populations of CWTD have been documented among certain islands and within associated bottomlands along the lower Columbia River, incorporating about 240 km² (93 mi²) of a predominantly tideland spruce community. At least one-half the estimated 300-350 CWTD occur on the mainland. Densities on the mainland were also positively correlated with percent woodland cover. Estimates of the refuge population ranged between 150 and 250 for the last 40 years; the Douglas County herd has experienced a 15-fold increase in range and a maximum 10-fold increase in population size during this same period. Lowland riparian systems have played a major role in CWTD distribution and abundance; in southwestern Oregon, they have served as corridors of dispersal and recent geographic expansion.

## Introduction

In the United States there are three subspecies of white-tailed deer (*Odocoileus virginianus*) that occur west of the Rocky Mountains: the Coues' whitetail (*O. v. couesi*) which inhabits southern Arizona and southwestern New Mexico; the Idaho whitetail (*O. v. ochrourus*) which occurs in western Wyoming and Montana, most of Idaho, and portions of eastern Washington and Oregon; and the Columbian whitetail (*O. v. leucurus*), an inhabitant of portions of southwestern Washington and northwestern and southwestern Oregon (Halls 1978). The Columbian white-tailed deer (CWTD), described by David Douglas in 1829 from two co-types collected in western Oregon, remains allopatric with the other western subspecies. The nearest geographic race, *O. v. ochrourus,* is approximately 300 km east of the range of *O. v. leucurus*.

Historically, CWTD occurred throughout much of western Oregon and southwestern Washington (Figure 1); Douglas (1829) reported that CWTD were common in the fertile prairies of the Cowlitz River and the Multnomah (Willamette) River within 100 miles of the Pacific Ocean. Douglas (1914) reported CWTD throughout the central river bottomlands of western Oregon as far south as the Umpqua River valleys. Both Bailey (1936) and Crews (1939) concluded that CWTD

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occurred as far south as Grants Pass, Oregon. CWTD apparently preferred the oak woodlands and mixed prairies of the oak-savanna complex, a vegetative association maintained by the native Indians through fire management (Thilenius 1968).

Extensive cultivation of western Oregon since early settlement has supplanted most of the native vegetation, leaving only patches of river bottomland associations adjacent to the largely agricultural lowlands (Thilenius 1968). Jewett (1914) and Bailey (1936) presented evidence that CWTD occurred in the Willamette Valley until late in the 19th century. Since then however, agricultural practices and curtailment of fires have dramatically altered the natural habitats (Thilenius 1968); CWTD have subsequently been extirpated from most of their historic range including the Willamette Valley.

Today, the distribution of *O. v. leucurus* is limited to two remnant populations: one is located along the lower Columbia River and the other inhabits the interior valleys of the Umpqua Basin in Douglas County, Oregon (Figure 1). The limited distribution of CWTD and imminent threat to remaining habitat by encroaching agricultural and residential development prompted the U.S. Department of Interior to designate *O. v. leucurus* as an endangered species in 1968 (Gavin 1979); the Douglas County population was listed in 1978. In 1972, the U.S. Fish and Wildlife Service (USFWS) purchased 2105 ha (5200 acres) along the lower Columbia River and established the Columbian White-tailed Deer National Wildlife Refuge (CWTDNWR). Since then there have been several studies directed at understanding the current status and ecology of *O. v. leucurus* (Suring and Vohs 1979, Gavin 1979, Dublin 1980, Smith 1981).

The purpose of this paper is to present information relating to the current geographic distribution and abundance of CWTD. Information pertaining to the population in southwestern Oregon was obtained during a study May 1978-December 1980; information regarding the lower Columbia River population comes from Gavin (1979) and the USFWS (1983).

#### Procedures

The geographic range of CWTD in southwestern Oregon was obtained by plotting new locations on U.S. Geological Survey topographical maps. Investigations were prompted by reports of CWTD in previously undocumented areas. The investigations involved spotlighting areas accessible by vehicle and/or traversing the area on horseback or on foot during early morning and/or evening hours. The geographic range was determined by connecting all the confirmed peripheral locations ($n = 16$) to form the smallest convex polygon (Jennrich and Turner 1969), but excluding the peripheral areas that were without locations and supported typically unsuitable CWTD habitat.

The occurrence of CWTD within areas along the lower Columbia River was documented by the USFWS, Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Game (WDG). Columbia River islands and mainland portions of Oregon and Washington where CWTD have been sighted since 1968 were recorded; the area encompassed by the smallest convex polygon enclosing all the documented locations served as an estimate of the total geographic range.

A study by Crews (1939) and observations recorded by Bill McCaleb (unpublished data, ODFW) during the 1950s and 1960s identified a region supporting

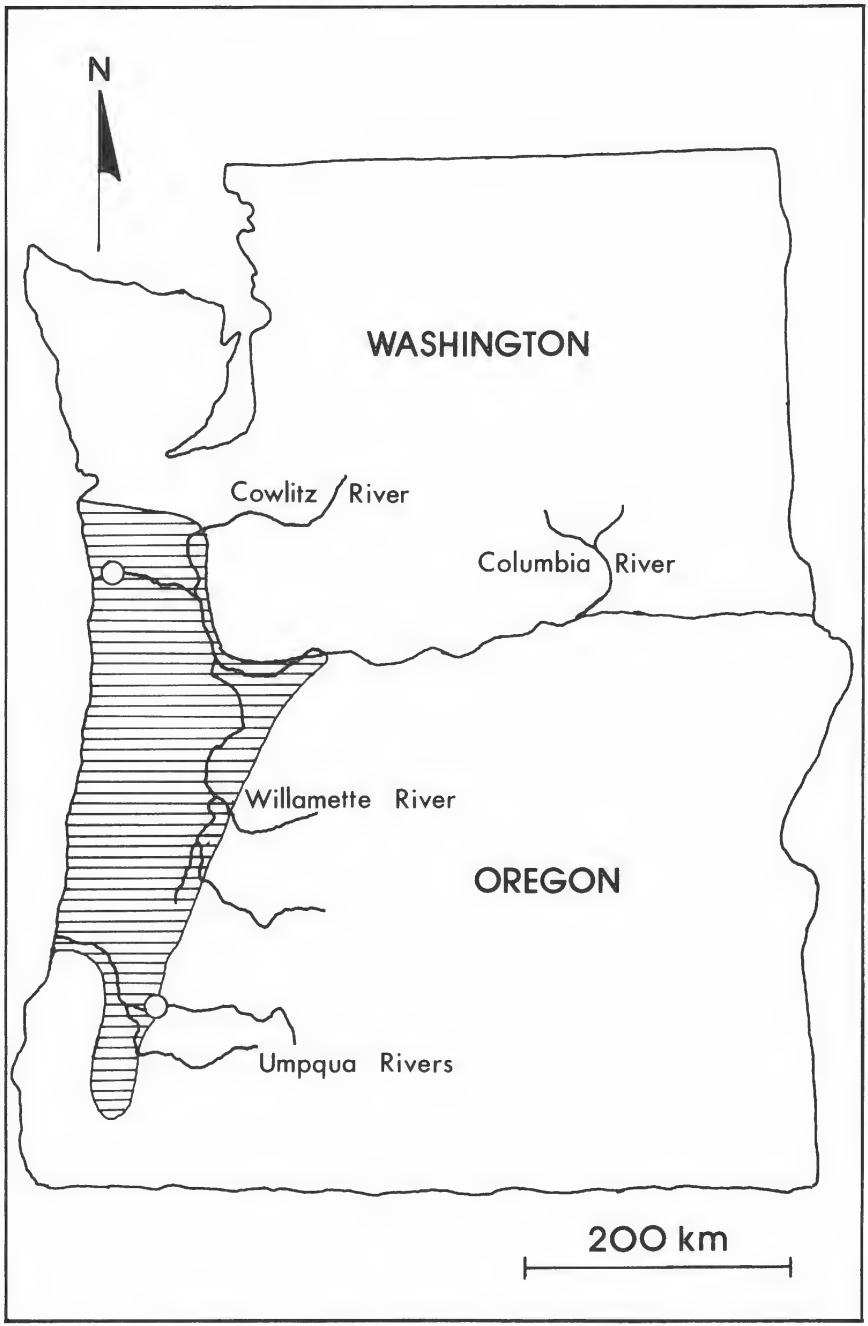


Figure 1. Historical distribution of Columbian white-tailed deer. (From Crews 1939.)

relatively high densities of CWTD and provided the basis for defining a 27.4 km² study area. From a marked sample of yearling and adult deer, the number of CWTD occurring within a 1.2 km² portion of the study area was estimated with the Schnabel capture-recapture ratio estimator (Chapman and Overton 1966); observations of marked individuals following capture served as recaptures. The total area occupied by this population and the corresponding density estimate were derived from the smallest convex polygon drawn around the peripheral locations of the marked cohort (Smith 1981). Comparable density indices were obtained for the remaining portion of the study area by conducting spotlight counts (CWTD per km) within four different regions simultaneously, including the part of the study area for which the Schnabel population estimate was derived. Assuming a correspondence between the Schnabel estimate and spotlight count, density indices were obtained for all portions of the study area represented by one of the four cover types (spotlight routes). To minimize the bias that might exist because of differences in observability of CWTD within the different cover types, a maximum identification distance and corresponding estimate of total area sampled was obtained for each spotlight route (Smith 1981). Similar density estimates were obtained for portions of the entire geographic range; maximum identification distance determined which of the cover type density indices was appropriate.

Gavin (1979) used the Schnabel mark-recapture technique to estimate the population size on the 7.9 km² mainland portion of the CWTDNWR. Population estimates for the remaining portion of the lower Columbia River range included on-the-ground and aerial surveys by the USFWS, members of the CWTD recovery team, Davison and Spencer (1979) and Davison (1979).

#### Results

Geographic Range

*Douglas County.* The geographic range of CWTD in southwestern Oregon (Figure 2) extended from Oldham Creek—8.0 km northeast of Oakland, south to Cow Creek—4.8 km southwest of Riddle. The southeastern-most observations were along Morgan Creek—1.5 km north of its intersection with the South Umpqua River; the northwest boundary extended to the town of Umpqua. The eastern and western boundaries were Fall Creek—0.5 km south of Little River, and Hawkins Lake (Bureau of Land Management), respectively. The total range encompassed 1199 km² (463 mi²). The CWTD distribution was not continuous throughout the range, owing to an interspersion of small mountains and associated forests. The highest densities occurred along the south bank of the North Umpqua River between Glide and Winchester, north of Buckhorn road (Figure 2).

The natural vegetation of the area is classified as *Quercus* Woodland community and is typical of the Interior Valley Zone of Western Oregon (Franklin and Dyrness 1973). This habitat type represents a diverse array of vegetative associations ranging from the sparsely stemmed stands of the oak-savanna, with predominately grass understories, to dense forests with well-developed mid-stories. Species composition varied from pure *Quercus* types to communities with an abundance of other hardwood and conifer associates, particularly *Arbutus menziesii, Acer macrophyllum, Pseudotsuga menziesii,* and *Pinus ponderosa* (Smith 1981). Smith (in

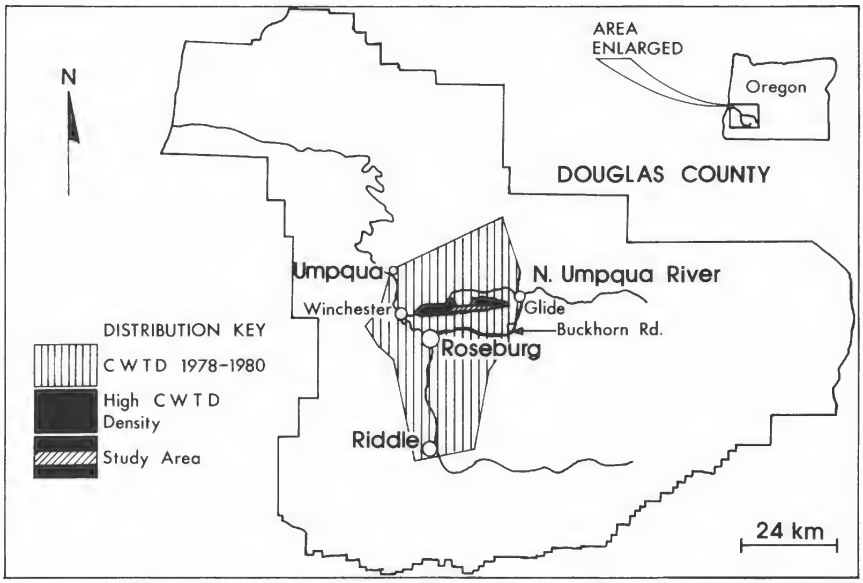


Figure 2. Current distribution of Columbian white-tailed deer in southwestern Oregon, May 1978-December 1980.

press) presents a complete description of the plant associations within the interior valleys of the North Umpqua River.

*Lower Columbia River.* The range of CWTD in northwestern Oregon and southwestern Washington is limited to certain islands and bottomlands along the 29 km stretch of the lower Columbia River between Wallace Island and Karlson Island (figure 3, from USFWS 1983), encompassing approximately 240 km² (93 mi²). About 65 km² (25 mi²) of this range is represented by the Columbia River and associated channels. The distribution of *O. v. leucurus* within the range is not uniform with virtually the entire known population distributed among five subpopulations: the mainland portion of the CWTDNWR at Cathlamet, Washington; Puget Island; Tenasillahe Island; Wallace Island and Westport, Oregon; and Karlson Island. About half the population occurs on the mainland portion of the CWTDNWR (USFWS 1983).

Gavin (1979) described the topography of the mainland CWTDNWR as flat with silty clay loam as the predominant soil type. The refuge mainland is part of the Columbia River flood plain and subject to tidal influences. The natural vegetation of the area is classified as a tideland spruce community within the *Picea sitchensis* Zone (Franklin and Dyrness 1973). Suring and Vohs (1979) have described the major plant communities on the refuge mainland.

## Relative Abundance

*Douglas County.* The distribution of *O. v. leucurus* was not uniform throughout the study area. Ninety percent of 12,031 observations occurred within 1 km of the North Umpqua River, only 50 percent of the entire study area ($P<0.05$,

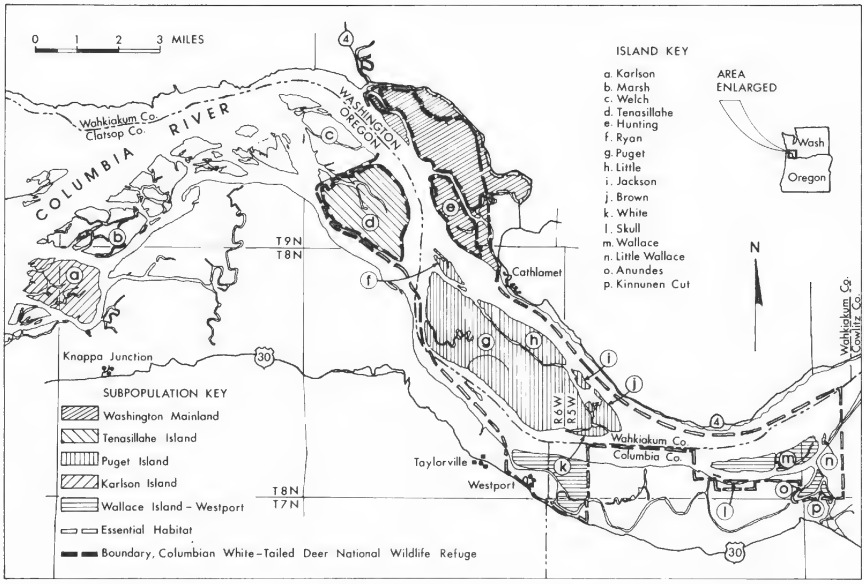


Figure 3. The five subpopulations of Columbian white-tailed deer, along the lower Columbia River. (From U.S. Fish and Wildlife Service 1983.)

Chi-square goodness-of-fit test, Snedecor and Cochran 1980). Within the *Quercus* Woodland types, CWTD density varied from 1.4 per km² along the periphery of the range to 35.2 per km² along the North Umpqua River lowlands. Also, the relative density of CWTD within portions of the study area varied in a positive curvilinear fashion ($r = 0.85$, $P < 0.05$) according to percent woodland cover; *O. v. leucurus* attained maximum densities in areas supporting at least 50 percent woodland cover. The population estimate for the 2745 ha study area was 592 ($s_{\bar{X}} = 15.8$, $n = 4$), representing an average density of 21.6 CWTD per km²; density estimates among the different cover types ranged 17.0 – 33.3 CWTD per km². The population estimate for the entire range in southwestern Oregon was 3000 CWTD.

*Lower Columbia River.* Gavin (1979) reported that *O. v. leucurus* estimates for the 790 ha refuge mainland ranged from 214 (127-370) in 1974 to 164 (92-306) in 1976. The distribution of deer throughout the refuge was not uniform; the number of deer per hectare was positively associated ($r = 0.99$) with percent woodland cover, attaining the highest densities in areas supporting at least 31 percent woodland cover (Gavin 1979). The USFWS (1983) estimated the mainland population to be between 150-200; corresponding estimates for the remaining subpopulations were Puget Island 50-75, Tenasillahe Island 30-50, Wallace Island-Westport 70-80, and Karlson Island 8-12, representing a total population estimate of 300-395 for the entire lower Columbia River range.

**Discussion**

In 1806, Lewis and Clark observed white-tailed deer along the Columbia River from the present location of The Dalles to Astoria along the coast (Thwaites 1905). Reported by several early naturalists, these western Oregon and Washington whitetails were designated a unique geographic race and remained abundant until settlement and development altered the native habitat. Since that time the geographic range and abundance of *O. v. leucurus* has steadily decreased; what once was a continuous distribution of CWTD throughout western Oregon and southwestern Washington encompassing over 60,000 km², has since been reduced to two remnant populations occupying less than 1500 km²—less than 2.5 percent of the historical range.

A commonality among local extirpations of CWTD has been the denudation of riparian associations. The importance of riparian systems to *O. v. leucurus* is suggested by several observations in Douglas County (Smith 1981). First, all but one of the peripheral locations defining the geographic range represent secondary or tertiary streams with much of the vegetation resembling native associations. And portions of the range where CWTD were absent were characterized by small mountains, coniferous forests and a paucity of riparian lowlands. Also, recent expansions in range (as suggested from ODFW annual spotlight censuses 1970-1984) have invariably been associated with streams and adjacent lowlands. The role of riparian systems in the life history of *O. v. leucurus* is not completely clear; Smith (1981) however, observed that female CWTD congregated along woodlands for fawning, and suggested that escape cover and forage quality were important for reproduction. It is apparent that riparian zones have served as corridors for dispersal, and further geographic expansion will depend upon the availability of these riparian avenues.

USFWS (1983) reported that CWTD numbers on the refuge mainland have remained fairly stable for the past 40 years. Scheffer (1940) and Lauckhart (1940) reported estimates of 250-350 and 200, respectively; the 1983 estimate was 235 (Al Clark, USFWS, unpublished data). Gavin (1979) suggested that the mainland refuge population was at stable equilibrium, and argued that neither the availability of quality forage nor predation were the forces responsible for maintaining the population well below its biotic potential. Instead, Gavin (1979) proposed that the mechanism responsible for balancing mortality and recruitment was a consequence of a relatively mild physical environment and a temporally homogeneous habitat. According to Gavin (1979), population stability was an outcome of individuals employing the most efficient life history tactics for the environmental regime within which they have evolved.

The Douglas County population has apparently increased and expanded its range during this 40-year period. Crews (1939) reported the distribution of "Oregon white-tailed deer" was limited to a small area northeast of Roseburg encompassing about 79 km²; he estimated the number of Oregon whitetails at 200-300 individuals. McCaleb (ODFW, unpublished data) estimated the number of CWTD within this region at 450-500 during 1970. ODFW spotlight censuses during this period documented a concomitant increase in geographic range. Current estimates indicate that CWTD have experienced a 15-fold increase in geographic range and

a maximum 10-fold increase in population size since 1939. Today, *O. v. leucurus* occupies approximately 25 percent of its historical range in Douglas County.

After a century or so of population decline and extirpation from most of its historical range, why have CWTD experienced a ten-fold increase in range and numbers in southwestern Oregon over the last 40 years? The available historical and biological evidence suggest that at least four factors probably contributed to the recovery of *O. v. leucurus* in Douglas County. The establishment and maintenance of the 6,000 ha "Oregon White-tailed Deer Refuge" during 1928-1952 afforded the remaining individuals protection and suitable habitat for recovery. The refuge was located within the high density portion of the current geographic range (Figure 2) and probably has served as the center of dispersal. It is very likely that the habitat has improved in the last half-century, particularly the availability of quality forage. Agricultural practices directed toward the development of improved pasture probably benefited deer as well as livestock. The clearing of oak woodlands created valuable forest-edge and enhanced the growth of young herbaceous and woody forage; the introduction of subterranean clover (*Trifolium subterraneum*), perennial ryegrass (*Lolium perenne*), and tall fescue (*Festuca arundinacea*) provided palatable and nutritious forage year round. Timber practices probably benefited CWTD also. Clear-cutting of adjacent coniferous forests created additional forest openings and increased the ratio of high quality forage to closed woody vegetation. And finally, CWTD may have benefited from the intense predator control practices that accompanied the development of livestock production in Douglas County. A. C. Clark (unpublished data, U.S. Fish and Wildlife Service) observed that coyotes (*Canis latrans*) can exert an intense predation pressure on young CWTD fawns. In a three-year telemetry study (1978-1980) of fawn mortality on the refuge mainland, Clark observed that 73 percent (33/44) of total fawn mortality was attributed to coyote predation. Yet predation in Douglas County represented less than two percent of CWTD fawn mortality during 1978-1980 (Smith 1981).

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# The Rationale Behind Wind Load Provisions in the Western United States, Past and Present

**Abstract**

A substantial portion of research activity in wind engineering is necessarily directed toward the improvement of codes and standards governing the design of buildings and structures. Unfortunately, a considerable time lag exists between advances in the state-of-the-art and reflection of this knowledge in the codes of practice. At present, many of the codes and standards in use in the United States have been just recently revised. The object of this paper is to examine the status of the wind load provisions contained in the recent revisions of some of these documents and compare them with those of a code which served the profession for almost three decades.

## Introduction

During the past two decades, profound changes in the state-of-the-art of wind engineering have evolved. These have occurred as a direct result of the development and widespread use of the turbulent boundary layer wind tunnel, the advancement of new probabilistic methods for treating randomly applied dynamic loads and reducing wind speed data, and the experience gained from the observed performance of existing buildings and structures subjected to extreme winds. Translation of this knowledge into the codes of practice, however, has presented a formidable task.

To gain acceptance by building code officials and practitioners alike, wind load provisions must, of necessity, be reasonably simple to apply, require a minimum of computational effort, and not be subject to misinterpretations. More importantly, they must ensure an acceptable level of risk within the constraints of economics. The engineer is faced with increased pressure from the American consumer who has become accustomed to a better product while insisting that costs be kept under control. As Casper (1981) so aptly states, " . . . a zero defects mentality now prevails throughout the United States—engineered structures are expected to perform perfectly." Although technology has provided the engineer and architect with new lightweight and high-strength materials to meet the challenge, economics dictates that the engineer strive for greater accuracy in the evaluation of loads. Unfortunately, the price to be paid for greater precision is that codes and standards governing the design of buildings and structures must necessarily

become more complex—the "projected area methods" must eventually go the way of the dinosaur.

In introducing new criteria, one must bear in mind that the old, somewhat simplistic treatments of the wind problem by various model building codes served the profession reasonably well for the vast majority of buildings and structures constructed over three decades; or have they? Practitioners argue that sophisticated standards such as ANSI A58.1 (1972) consider parameters which, in many cases, lead to an assumed accuracy of design far more precise than knowledge warrants. They are also alleged to require an amount of engineering effort which is often difficult to justify.

During the past few years, there has been a great deal of activity by various organizations directed towards the improvement of wind design criteria. Revisions of various codes and standards have just recently been presented to the profession. The object of this paper is to examine a number of these revisions, provide a brief account of the rationale behind each and compare the end results, i.e., the actual design loads, with those of a code which was in widespread use over the past 29 years, the Uniform Building Code (1979). Specifically, revisions of this code (1982), the revisions of the American National Standards Institute Standard ANSI A58.1 (1982), and the recently published industrial standard for metal buildings (1981) will be discussed. For brevity, these documents will be referred to hereafter as UBC-79, UBC-82, ANSI-82, and MBMA-81, respectively.

#### Basic Assumptions Involved in Developing Wind Criteria

Background

Traditionally, code and standard writers in the United States have used a simple relationship between free stream wind flow conditions and the corresponding pressures induced on the surface of a building or structure as given by

$$p_z = \frac{1}{2}\varrho V_0^2 K_z G_z C_p \tag{1}$$

in which,

$p_z$ = pressure induced at height z above mean ground level, psf

$\varrho$ = mass density of air $\left[\frac{1}{2}\varrho = 0.00256 \text{ at } 15°\text{C and } 760 \text{ mm}\right]$

$V_o$ = basic design wind speed at some reference height $z_o$ above mean ground level, mph

$K_z$ = exposure coefficient to account for variation in velocity with height z above mean ground level as influenced by terrain exposure

$G_z$ = gust response factor intended to account for load amplification due to turbulence in the approaching wind and turbulence generated as the result of the interruption of the flow pattern by a building or structure in the wind path (in later standards this term has been expanded to include the effect of resonant vibrations of the structure)

$C_p$ = external mean pressure coefficient (or shape factor) averaged over some time interval

In the design of "components and cladding" some standards have attempted to include the influence of internal pressure fluctuations due to planned or unplanned openings or gross building permeability and have modified equation (1) to read:

$$P_z = \frac{1}{2} \varrho V_0^2 K_z G_z (C_p - C_{pi}) \tag{2}$$

where,

$C_{pi}$ = internal pressure coefficient

The degree of sophistication involved in evaluating the parameters contained in each of the above equations for a given design application constitutes the point of departure in codifying wind effects. As our basic understanding of the effects of wind on structures has improved, the tendency has been to introduce refinements (and attendant complexities) in the evaluation of each of the terms. Obviously, some trade-offs are necessary in order that reasonably simple wind load criteria can be developed which are applicable for a majority of conventional type structures encountered in practice. Table 1 presents an outline of the basic factors considered in the evaluation of each of these items by the various codes and standards discussed in this paper. A detailed presentation follows.

#### Basic Design Wind Speed

Perhaps the most important parameter in evaluating wind loads is the basic design wind speed $V_o$. All four documents considered utilize the fastest-mile wind speed (mph) evaluated at a reference height $z_o$ above mean ground level. UBC-79, UBC-82, and MBMA-81 reference speeds to a height $z_o$ of 30 ft, while ANSI-82 uses 33 ft; the difference due to this height variation is small. There are, however, other differences as will be noted.

1) *UBC-79*

To simplify the computations involved in arriving at loads, UBC-79 used a wind pressure map for the contiguous United States developed by Brekke (1959) and incorporated in ASA A58.1 (1955). In developing the map, wind speeds were based on the records of 155 NWS stations. The actual values used corresponded to the "peak" fastest-mile speeds reported during the 39 years of record prior to 1952. The data were normalized to a standard 30 ft height for flat, open country terrain. To convert the wind speeds into design wind pressures the following assumptions were employed:

a) a "gust factor" (as opposed to a "gust response factor") $G_{30}$ equal to 1.3 at a height $z_o$ = 30 ft was assumed to account for excursions above the fastest-mile speed (to obtain a "gust speed"), and

b) a constant shape factor $C_R$ = 1.3 was assumed.

Thus, the wind pressure map of UBC-79 was based upon the equation

$$p_{30} = \frac{1}{2} \varrho [G_{30} V_{30}]^2 C_R = 0.00256 [1.3 V_{30}]^2 (1.3) \tag{3}$$

TABLE 1. Comparison of basic design parameters considered in codes and standards.

| | $p_z = \overbrace{\frac{1}{2}\rho (IV_{33})^2 K_z G_z C_p}^{q}$ | $p_z = \overbrace{\frac{1}{2}\rho (V_{30}^2)(\frac{H}{30})^{2/7} C_p}^{q}$ | $p_z = \frac{1}{2}\rho (G_H V_{30})^2 (\frac{H}{30})^{2/7} C_R$ | $p_z = \overbrace{\frac{1}{2}\rho (V_{30}^2) C_e C_q I}^{q_s}$ |
|---|---|---|---|---|
| Factors Considered | ANSI A58.1-1982 | MBMA-1981 | UBC-1979 | UBC-1982 |
| WIND SPEED -Mean Speed | Fastest-Mile (50 yr. M.R.I.) | Fastest-Mile (50 yr. M.R.I.) | Fastest-Mile (39 yr. peak) | Fastest-Mile (50 yr. M.R.I.) |
| -Importance Coefficient | Yes | Yes (In COMMENTARY) | No[a] | Yes[a] |
| TERRAIN EXPOSURE | $K_z$(Exp. A,B,C,&D) | Exposure B,C (1/7 Exponential) | Exposure C (1/7 Exponential) | $C_e$ (Exp. B,C)[b] (Combined Height, Exposure and Gust Factor Coefficient) |
| GUST RESPONSE FACTOR | | | | |
| -Variation With Height | $G_z$ | No | $G_H$ (varies from 1.3 - 1.08)[c] | $C_e$[b] |
| -Dynamic Provisions for Flexible Structures | Yes | No | No | Yes (recommends ANSI A58.1-82) |
| WIND LOAD DETERMINATION | | | | |
| -Separate Provisions for Components and Cladding) | Yes | Yes | No | Yes |
| PRESSURE/FORCE COEFFICIENTS | | | | |
| -Gross Structure | $C_p$ | $(GC_p)$ | $C_R$ = 1.3 (constant)[d] | $C_q$ |
| -Component and Cladding Coefficients Function of Tributary Area | Yes | Yes | No | No[e] |
| -Internal Pressure Coefficients for Components and Cladding | $C_{pi}$ | Combined with $C_p$ | No[f] | Combined with $C_q$ |

NOTES:

a) Reduction in loads for "Miscellaneous Structures"

b) $C_e = K_z G_z$ (combined height, exposure and gust response factor)

c) $G_H$ accounts for gust speed of wind only

d) $C_R$ = net drag coefficient for buildings, multiplying factors given for chimneys, tanks and towers

e) However, separate coefficients provided for components and fasteners

f) However, separate provisions provided for "unenclosed structures"

TABLE 1 continued

NOMENCLATURE:

$C_e$: Combined Height, Exposure and Gust Factor Coefficient

$C_p$: External Pressure Coefficient, ANSI-82

$C_P$: Product of Gust Response Factor and External and Internal Pressure Coefficients, MBMA-81

$C_q$: Combination External and Internal Pressure Coefficients

$C_R$: Shape Factor = 1.3

$G_H$: Gust Factor at Height H

$G_z$: Gust Response Factor

H: Mean Roof Height

I: Importance Coefficient

$K_z$: Exposure Coefficient

q: Velocity pressure; ANSI-82 MBMA-81

$q_s$: Stagnation pressure, UBC-82

$V_{30}$: Basic Design Wind Speed at 30 ft Above Mean Ground

$V_{33}$: Basic Design Wind Speed at 33 ft Above Mean Ground

$\varrho$: Mass Density of Air

where $p_{30}$ is the basic reference pressure and corresponded to the peak 39 year fastest-mile speeds. It should be noted that $G_{30}$ replaced $\sqrt{G_z}$ in Equation 1 evaluated at height z = 30 ft and $C_R$ represented the net (drag) coefficient.

2) **UBC-82, ANSI-82 and MBMA-81**

In updating the 1972 version of the ANSI Standard, the basic wind speeds were established from data collected at 129 weather stations for the mainland United States. The data were statistically reduced by Simiu, *et al* (1979), using extreme value analysis procedures based upon a Fisher-Tippet Type I (Gumbel) distribution. Wind speed values are given in the form of a map for the contiguous United States and Alaska (Figure 1) and in tabular form for Hawaii and Puerto Rico. The values correspond to the annual, extreme fastest-mile speeds for an annual probability of exceedence of 0.02 (50 year mean recurrence interval). The wind speed contours along the hurricane-prone coastline are based on a recently completed analysis of hurricane winds by Batts, *et al* (1980).

The new industrial standard MBMA-81 and UBC-82 utilize the ANSI-82 map in prescribing the basic design wind speed.

#### Importance Factor

To account for operational usage, the 1972 version of the ANSI Standard provided wind speeds for 25, 50 and 100 year mean recurrence intervals (probability of exceedence levels of 0.04, 0.02 and 0.01, respectively). To replace the need to provide three separate maps and in an attempt to assign a consistent level of risk associated with all environmental loads (wind, snow and earthquake), ANSI-82 introduces for the first time an importance factor I in Equation 1. The term $V_0^2$ is replaced by $(IV_{33})^2$. All buildings and structures are categorized in terms of operational usage by the classification scheme presented in Table 2. The importance factor I was then established for wind, snow and earthquake loads as a function of the statistical characteristics of each, the manner in which the structure responds to the loads, and the consequences of failure. For wind loads, the importance

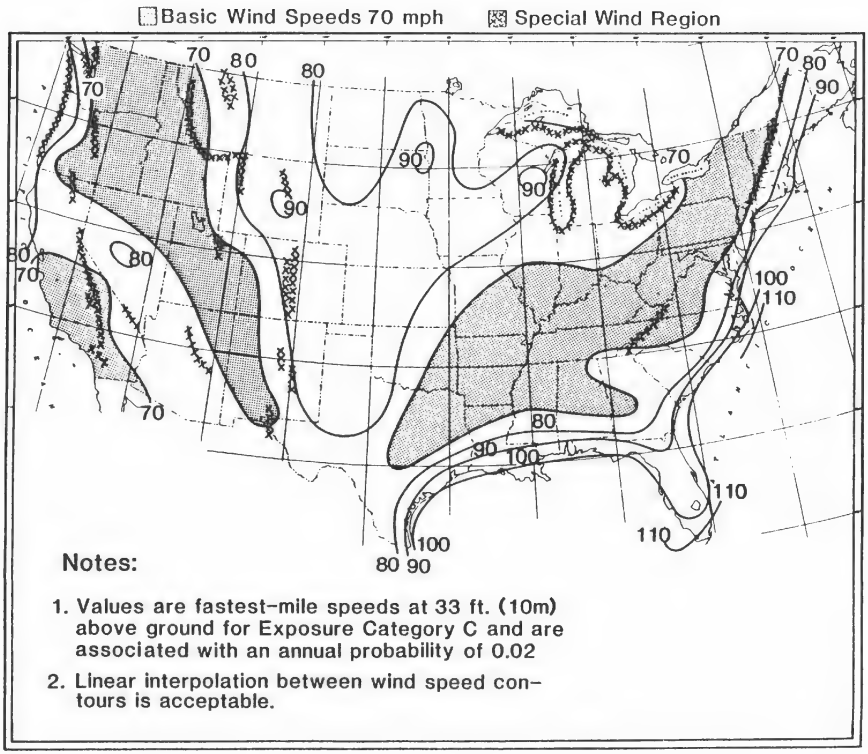

Basic Wind Speeds 70 mph
Special Wind Region
70
80
90
100
110
Notes:
1. Values are fastest-mile speeds at 33 ft. (10m) above ground for Exposure Category C and are associated with an annual probability of 0.02
2. Linear interpolation between wind speed contours is acceptable.

Figure 1. Basic wind speed (fastest-mile) in mph (ANSI A58.1 Wind Load Subcommittee, 1980).

TABLE 2. Classification of buildings and other structures for wind, snow and earthquake loads.

| NATURE OF OCCUPANCY | CATEGORY |
|---|---|
| All Buildings and Structures Except As Listed Below | I |
| 300 People or More | II |
| Essential Facilities | III |
| Low Hazard | IV |

factor I provided in Table 3, in effect, adjusts the wind speeds provided in the standard based on an annual probability of exceedence of 0.02 (50 year mean recurrence interval) to other levels of probability. Thus, coefficients of 1.07 and 0.95 are associated with annual probabilities of exceedence of 0.01 and 0.04, respectively. The importance factors listed in Table 3 for the hurricane-prone coastline reflect the difference in probability distributions of hurricane wind speeds and those of inland regions. MBMA-81 does not introduce an "I term" into Equation 1

TABLE 3. Importance factor.

| Structure Classification Category | Importance Factor, I | |
|---|---|---|
| | 100 miles inland | Hurricane oceanline |
| I | 1.00 | 1.05 |
| II | 1.07 | 1.11 |
| III | 1.07 | 1.11 |
| IV | 0.95 | 1.00 |

but does present in the commentary the classification scheme and importance factors employed in ANSI-82.

As can be seen from Table 1, UBC-82 introduces an importance factor I in the basic equation to be used in the determination of "Design Wind Pressures"

$$p = C_e C_q q_s I \tag{4}$$

Note that the values of this coefficient correspond to the square of the values given in ANSI-82.

UBC-82 also contains a provision for "miscellaneous structures." Section 2311 (q) specifies a design load of three-fourths of that calculated using the 50 year design speed for greenhouses, agricultural buildings, or fences. This reduction is approximately comparable to changing the wind return period from 50 to about 25 years. UBC-79 provided a similar provision but specified a design load reduction of one-third rather than one-fourth.

#### Terrain Exposure

The velocity exposure coefficient $K_z$ is introduced into Equation 1 to take into consideration the variation of velocity with height as a function of ground roughness. ANSI-82 provides for four exposure categories A, B, C, and D as depicted in Figure 2. The coefficient $K_z$ is given by

$$K_z = \begin{cases} 2.58 \left(\dfrac{z}{z_g}\right)^{2/\alpha} & \text{for } z \geq 15 \text{ ft} \\ 2.58 \left(\dfrac{15}{z_g}\right)^{2/\alpha} & \text{for } z \leq 15 \text{ ft} \end{cases} \tag{5}$$

in which,

$z$ = height above mean ground level, ft

$z_g$ = gradient height given in Table 4, ft

$\alpha$ = exponential factor given in Table 4

TABLE 4. Exposure category constants.

| Exposure Category | $\alpha$ | $z_g$ | $D_o$ |
|---|---|---|---|
| A | 3.0 | 1500 | 0.025 |
| B | 4.5 | 1200 | 0.010 |
| C | 7.0 | 900 | 0.005 |
| D | 10.0 | 700 | 0.003 |

Figure 2 compares the mean speed variation with height for each of these four categories based upon a basic design speed of 100 mph for exposure C. It is seen that the selection of an appropriate exposure category significantly affects the design load as the velocity is squared in Equation 1. Thus, the design pressures for exposure categories A and B could be less than 20 and 51 percent of category C pressures at a height of 33 ft for the same basic design wind speed. On the other hand, design pressures for exposure D could be greater by 139 percent. UBC-82 specifies two exposures B and C and combines the gust factor $G_z$ with the terrain exposure coefficient $K_z$ to yield a table of coefficients (Table 23-G):

$$C_e = K_z G_z \tag{6}$$

The provisions of UBC-79 and MBMA-81 are based upon flat, open country conditions (exposure C), although the pressure coefficients given in MBMA-81 have been shown by Davenport, *et al* (1977, 1978, 1979) to be applicable for exposure B.

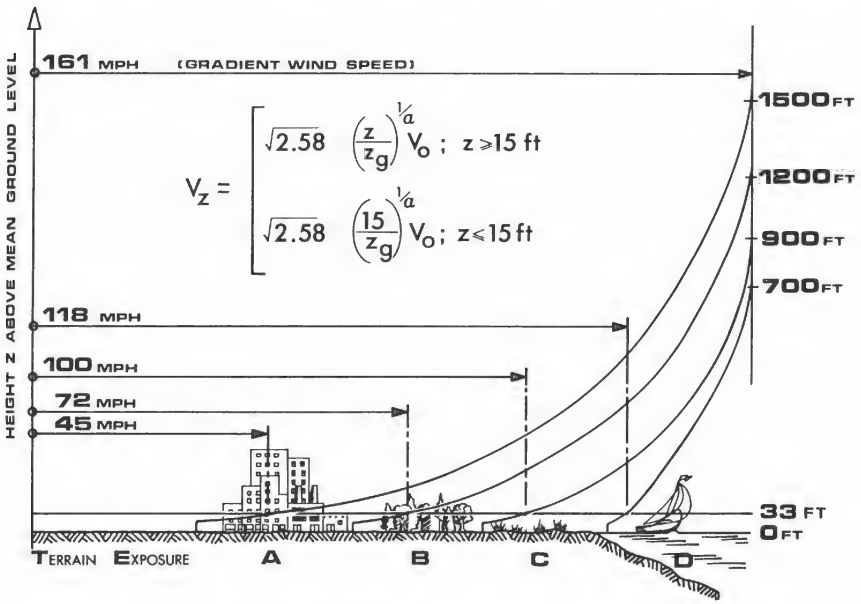



Figure 2. Mean wind speed variation with height.

**Gust Response Factor**

Experience and wind tunnel experiments have confirmed that induced wind pressures are transient and fluctuate markedly with respect to both time and space. In order to convert transient loads into equivalent static design loads the gust response factor $G_Z$ is introduced in Equation 1. Thus, $G_Z$ represents a magnification coefficient to account for turbulence in the approaching wind field (gustiness) and turbulence generated as the result of interruption of the flow pattern by a building or structure in the wind path.

**1) ANSI-82**

The 1972 version of the ANSI Standard utilized the expression developed by Vellozzi and Cohen (1968):

$$G_Z = 0.65 + 3.31T_ZR \tag{7}$$

in which the turbulence intensity factor $T_Z$ is given by

$$T_Z = \frac{2.35(D_O)^{1/2}}{\left(\frac{z}{30}\right)^{1/\alpha}} \tag{8}$$

and the surface drag coefficient $D_O$ and power law coefficient $\alpha$ are specified in Table 4. The response factor R is largely dependent on the size, gross geometry and dynamic response characteristics of the structure relative to the frequency content of the approaching wind. In developing the 1972 version of the standard, simplified expressions of the response factor R were used. For structures not sensitive to the wind, that is, not susceptible to oscillations, R was taken as 1.2 for the design of "main framing" and 1.5 for "parts and portions." Hence Equation 7 was reduced for the determination of loads for the "main framing" to

$$G_Z = 0.65 + 3.97T_Z \tag{9}$$

and for "parts or portions" to

$$G_Z = 0.65 + 4.96T_Z \tag{10}$$

For those flexible buildings or structures for which amplification in loading might be produced as a result of along-wind induced vibrations, the gust factor to be used in the determination of gross loading for the design of "main frames" was given in the 1972 version of the standard as

$$G = 0.65 + 1.96(\alpha\sqrt{P}) \geq 1.0 \tag{11}$$

where $\alpha\sqrt{P}$, the ratio of the standard deviation of the wind loading to the mean wind loading, is dependent upon the properties of the gust loads and the structural response.

To simplify the computation of design wind loads, ANSI-82 adopted the following procedure for evaluation of the gust response factor:

a) for the determination of wind loading influencing the design of the "main wind-force resisting systems," $G_Z$ is given by:

$$G_z = 0.65 + 3.65T_z \quad (12)$$

however, this term is to be evaluated at z = h and assumed constant over the height of the building;

b) for the design of "components and cladding," appropriate coefficients ($GC_p$) have been specified thus eliminating the need to separately compute G; and

c) for those buildings and structures susceptible to wind-induced oscillations, several methods for determination of a "dynamic gust factor" $\overline{G}$ are provided in the appendix.

Item b) above reflects the trend in recent wind tunnel investigations in which coefficients $GC_p$ are generated which represent the product of the gust response factor and pressure coefficient. Thus, the instantaneous pressures induced on the structure or portion thereof are integrated with respect to both time and over the surface area of interest. Further discussion of this innovative procedure will be given in the section dealing with pressure coefficients.

#### 2) UBC-82

This code utilizes Equation 9 for the determination of the gust response factor and, as noted above, combines this term with the terrain exposure coefficient to yield a table of the factor $C_e = K_z G_z$. For buildings and structures sensitive to dynamic effects and for buildings over 400 ft in height, the code requires design procedures in accordance with "recognized national standards" (presumably ANSI-82).

#### 3) UBC-79

As noted earlier, this code employed a "gust factor" $G_H$ to convert fastest-mile speeds to "gust speeds" in accordance with the relation $V_z$ (instantaneous) = $G_H V_z$ (fastest-mile). It should be noted that the gust factor, which was assumed to vary with height from 1.3 at 30 ft to 1.14 at 500 ft and 1.08 at 1200 ft, did not reflect turbulence generated at the surface of the building or structure as the result of the interruption of the free field wind flow, nor account for load amplification due to resonant vibrations.

#### 4) MBMA-81

This industrial standard is based upon the extensive series of wind tunnel investigation conducted at the University of Western Ontario from 1975 to 1978. In developing appropriate wind load criteria, no attempt was made to separate out the gust response factor $G_z$ from the pressure coefficient $C_p$ in Equation 1. Thus, the coefficients provided in this design manual represent the product of these two terms ($CG_p$) and eliminate the need to calculate the gust response factor term separately.

### Pressure Coefficients

Historically, pressure coefficients $C_p$ have been defined as the non-dimensional ratio of the wind-induced pressure $p_z$ at a point on the surface of a building or structure to the kinetic energy of the air as given from Equation 1 by:

$$C_p = \frac{P_z}{\frac{1}{2}\varrho V_o^2 K_z G_z} \tag{13}$$

Experience has shown that induced pressures are transient and are not well organized with respect to either time or space. To obtain equivalent static design loads it is necessary, therefore, to integrate the pressures over some time interval as well as over the surface area of interest.

Wind tunnel tests and full-scale studies have confirmed that the effect of localized turbulence decreases with increasing area. The loading experienced by a structural component having a relatively small tributary area (e.g., a purlin, girt, etc.) may be much higher than that seen by the "main wind-force resisting systems" (e.g., rigid frames, shear walls, diaphragms, etc.) which receive wind loading which may originate at locations relatively remote from the system itself and over a large portion of the structure. Thus, to be precise, the pressure coefficients prescribed in codes and standards should be specified as a function of the direction of the wind, gross building geometry, tributary surface area for the structural component or assemblage of interest, and the location of this element relative to the surface discontinuities of the building. The degree of complexity involved in attempting to incorporate the above factors in some reasonably simple, yet rational manner, constitutes a significant point of departure in the various codes and standards discussed in this document.

#### 1) ANSI-82

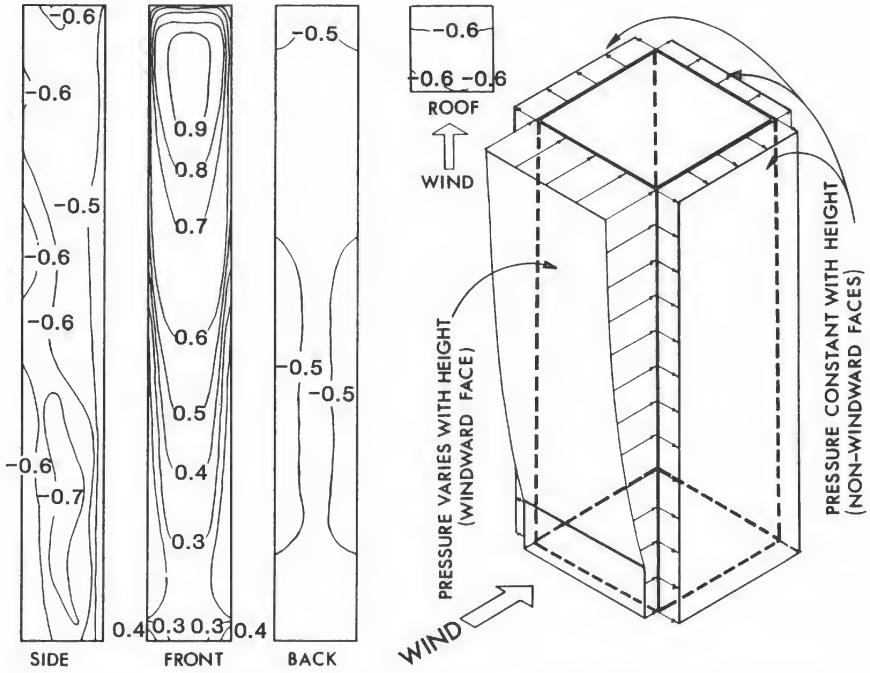
This revision places greater emphasis on the separation of global wind loads applicable for the design of the "main wind-force resisting systems" and those to be used for "components and cladding" than did the 1972 version. The approach effects a reduction in wind loading for the primary load resisting systems. "Components and cladding" are required to be designed for higher loads but with the loads decreasing as the tributary area increases.

As noted previously, the trend in recent wind tunnel investigations has been to generate external and internal coefficients which represent the product of the gust response factor $G_z$ and external and internal pressure coefficients $C_p$ and $C_{pi}$, respectively. Such coefficients, which are denoted as $(GC_p)$ and $(GC_{pi})$, eliminate the need to evaluate the gust response factor. This approach is desirable but requires more elaborate wind tunnel tests in order to properly account for all ground roughness categories. Regrettably, a mix of these coefficients occurs in the standard.

The essential features of the pressure coefficients given based upon wind tunnel tests by Surry and Davenport (1979) for low-rise buildings and Cermak (1977) for high-rise buildings, include the following noteworthy items:

a) External pressure coefficients $C_p$ and $(GC_p)$ are assigned for a particular surface or portion thereof and are assumed to be uniformly distributed (have the same numerical value) over the zone considered. Note, however, that the induced pressures vary with respect to height for a windward face, but are constant with respect to height above ground for non-windward faces as shown

in Figure 3. Wind tunnels have confirmed that this is a reasonable approximation provided the pressures for non-windward surfaces are referenced to mean roof height.




a) External pressure coefficients measured in wind tunnel.

b) Assumed distribution of external wind pressures.

Figure 3. Monitored pressure coefficients and assumed code pressures.

b) For the determination of loads for the "main wind-force resisting systems," the external pressure coefficients $C_p$ are specified for a given wind direction and various building aspect ratios. Thus, a minimum of two loading conditions must be considered, e.g., for principal axes of the building. Fluctuations in internal pressures should also be considered for single-story buildings.

c) For the determination of loads for "components and cladding," the external coefficients ($GC_p$) given in the standard have been both time and spatially averaged to provide coefficients as a function of the tributary area of interest. The values presented represent the envelopes of the maximum positive and negative coefficients for all possible wind directions as depicted in Figure 4. Thus, two load conditions must be considered.

d) In developing the internal pressure coefficients ($GC_{pi}$) given in the standard, the envelope approach has again been used. A maximum of two load conditions must therefore be considered (maximum positive and negative coefficients). If the failure of doors or windows during severe winds is considered as a possibility, other load cases could result.

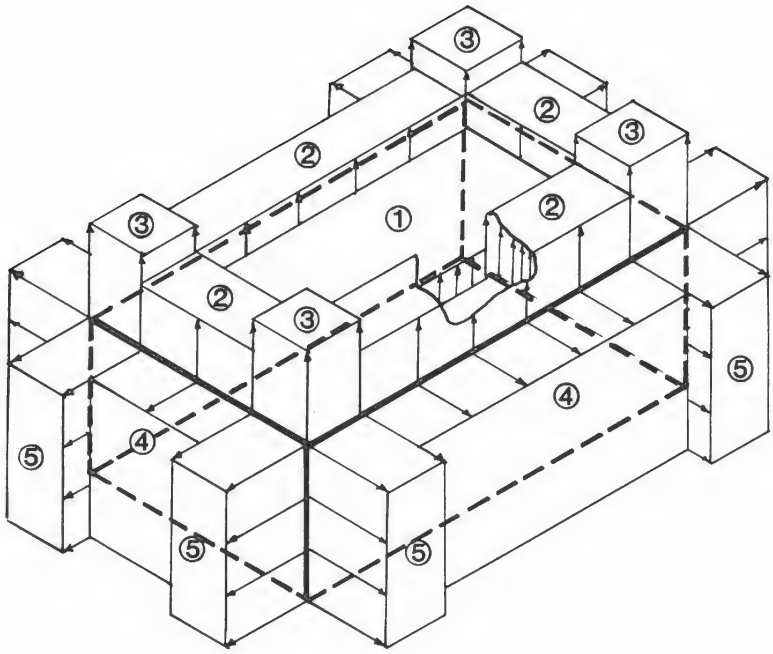



Figure 4. Envelope of maximum negative external pressures for component and cladding design.

**2) UBC-82**

The revision of this code offers major improvements over UBC-79 while retaining some ties with the past. The traditional method of specifying wind forces for buildings by applying horizontal pressures upon the vertical projected area and vertical uplift forces upon the horizontal projected area has been retained as an alternate procedure (Method 2) for the design of structures less than 200 ft in height (except those using gabled rigid frames). The primary method for determining wind loads (Method 1) is patterned after ANSI A58.1-72; but, some attempt has been made to include the philosophy of the provisions contained in the revision of this standard. For the first time, the code clearly separates the loads to be used in the design of "primary frames and systems" from those to be used for "elements and components."

In specifying pressure coefficients to be used, the following items are noteworthy:

a) Outward (negative) pressures are considered constant over the height of the buildings and are referenced to the velocity at mean roof height.

b) For the design of "primary frames and systems" internal pressures have been omitted for "enclosed structures" and the internal pressure coefficient is taken as 0.5 for "partially enclosed structures."

c) For the design of "elements and components," the pressure coefficients $C_q$ given represent the vector sum of external and internal pressures in Equation 2, i.e., $C_q = (C_p - C_{pi})$, by assuming a constant internal pressure coefficient of 0.4 for "enclosed structures" and 0.9 for "partially enclosed structures."

d) For the design of "elements and components" an attempt has been made to recognize that pressure coefficients should reflect the tributary area and location of the element being considered. The coefficients provided are based upon the provisions of ANSI A58.1-72 for a tributary area of 200 sq ft for the design of elements and 10 sq ft for cladding connections. Separate coefficients are provided for local areas at surface geometric discontinuities of the building (wall corners, eaves, rakes, etc.).

#### 3) UBC-79

This code was based on the old traditional method of applying wind loads to the vertical and horizontal projected areas of the building or structure. Horizontal design pressures were based upon a "shape" or "net drag" pressure coefficient $C_R$ of 1.3 which was incorporated into the wind pressure map as noted earlier. Additional shape or multiplying factors were given for chimneys, tanks and towers. Uplift design pressures were specified as three-fourths of the pressures set forth in the wind pressure map and were assumed to act in a direction normal to the surface of the roof.

Practitioners argue and will continue to argue that this simplistic procedure worked well for most structures and the method will undoubtedly be around in some form or another for years to come. Perhaps its greatest weakness is that it does not specifically address the question of design wind loading for "components and cladding" which experience has shown should be designed for higher wind loads than the "primary systems and frames." No provisions were specified for fluctuations in internal pressures except for the case of unenclosed buildings, roof overhangs, canopies, etc.

#### 4) MBMA-81

The provisions contained in the MBMA Standard present perhaps the most innovative approach to the determination of wind load criteria yet introduced. The provisions were developed based upon extensive wind tunnel tests conducted at the University of Western Ontario under the sponsorship of MBMA, AISI and Canadian SICC, previously referenced (1977, 1978, 1979).

The tests were tailored for the conventional low-rise rigid frame building with and without eave overhangs. The procedure followed consisted essentially of permitting the building model to rotate in the wind tunnel through a full 360° while monitoring the load conditions on each of the surfaces. Using influence coefficients for rigid frames it was possible to spatially- and time-average the induced pressures to ascertain the maximum induced force components to be resisted. More specifically, the following structural force components were evaluated:

a. total uplift,
b. total horizontal shear,
c. bending moment at knees (2-hinged frame),

d. bending moment at knees (3-hinged frames), and
e. bending moment at ridge (2-hinged frame).

The approach followed was then to develop a set of "pseudo" pressure coefficients to generate a loading condition which would envelope the maximum induced force components to be resisted for all possible wind directions. (Note, for example, that the wind azimuth producing the maximum bending moment at the knee would not necessarily produce the maximum total uplift.) The maximum induced force component determined for each of the above five categories was used to develop the coefficients. The end result was a set of pressure coefficients which represents a somewhat fictitious loading condition, but one which conservatively predicts the maximum induced force components (bending moment, shear, and thrust) to be resisted (independently of wind direction).

In developing the set of pressure coefficients applicable for the design of "components and cladding," an envelope approach was again used. A set of pressure coefficients were determined based upon time and spatial averaging methods as a function of gross building geometry, tributary area of the part or element being considered, and location of the element relative to the boundaries of the building. Envelopes of maximum positive and negative pressure coefficients were developed for specific zones of the building as depicted earlier in Figure 4. It should be noted, however, that the coefficient values were determined independently of framing considerations.

The coefficients first developed were based upon the most critical wind direction, the most critical building geometry, and the most unfavorable terrain conditions. To reflect the probability of occurrence that the most severe wind, approaching the building from the most severe direction and the most critical combination of dimensions and terrain conditions could occur simultaneously, prompted Davenport and Surry (1979) to adjust the coefficients to the 80 percentile of the maximum values measured in the wind tunnel. ANSI-82 adopted the maximum coefficients developed but did not elect to reduce the coefficients by 20 percent. Good arguments have been presented by Davenport and Surry (1979), however, in support of this reduction.

In addition to the items discussed above, other important features of the pressure coefficients given in this standard include the following items:

a) For the determination of loads for the "main wind-force resisting systems," pressure coefficients have been specified for interior and end zones of the building. All pressures are assumed to be uniformly distributed over the zones of interest (do not vary with height) and are referenced to the wind velocity at mean roof height.

b) For the determination of loads for design of "components and cladding," the coefficients provided include an internal "bursting" pressure coefficient of $\pm 0.2$ and an additional $\pm 0.4$ for "partially enclosed buildings."

c) Separate roof overhang coefficients are provided which include contributions from both the upper and lower surfaces. Presumably these coefficients should also be used for design of "main wind-force resisting systems" where applicable.

d) For the design of foundations, but exclusive of anchorages to the frames, it is suggested that 70 percent of the wind load from the frames be considered as effective.

### Design Example

In the previous sections the assumptions on which the wind load provisions of each of the codes and standards are based have been summarized. It proves impossible to compare the provisions of one against the other except at the end results, that is to state, the actual design loads. A critical comparison would obviously require consideration of a large number of buildings and structures having different gross geometry and structural framing characteristics and sited in a variety of terrain exposures. Such a detailed examination is beyond the scope of this paper. Rather, a single design example has been selected which is representative of a high percentage of low-rise buildings constructed in the United States at the present time. Figure 5 presents a summary of the gross dimensions of the building.

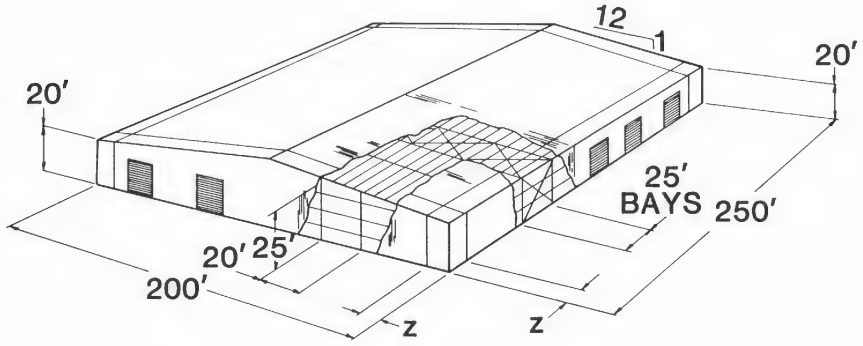


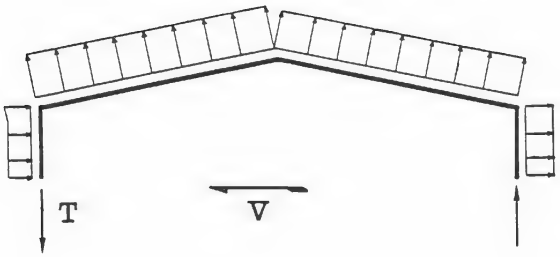

Figure 5. Building geometry.

Framing considerations are not addressed except that for determining "component and cladding" loads, a tributary area of 125 sq ft has been assumed for the purlins and girts and 5 sq ft for the fasteners in the case of the low-rise building. An importance coefficient I equal to 1.0 has been assigned.

### Main Wind-Force Resisting Systems

In applying the provisions of ANSI-82, two cases have been considered corresponding to internal pressure coefficients $C_{pi} = \pm 0.25$. Figure 6 presents a comparison of the gross base shear V and the maximum anchorage force T (per lineal foot of building) for exposure categories B, C and D, and an internal pressure coefficient $C_{pi} = +0.25$ (for ANSI-82). To provide insight into the magnitude of variation of these force components as prescribed by the various codes and standards, the forces are normalized in terms of the appropriate force component determined on the basis of ANSI-82, exposure C. It should be noted that for the geographic location considered, UBC-79 values are based upon a basic reference pressure of 20 psf which corresponds to a wind speed of 60 mph as compared to 70 mph for all others.

In terms of the base shear V, it is seen that UBC-79 predicts a value 25 percent higher than ANSI-82, while MBMA-81 yields the lowest values (for both interior




| FORCE COMPONENT | | ANSI-82 | | | UBC-82 | | | | UBC-79** | MBMA-81 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Method 1 | | Method 2 | | | Interior Frame | End Frame |
| | | B | C | D | B | C | B | C | C | B,C | B,C |
| BASE SHEAR | V(plf) | 195 | 340 | 446 | 250 | 420 | 349 | 589 | 425 | 146 | 212 |
| | Ratio* | .57 | 1.0 | 1.31 | .74 | 1.24 | 1.03 | 1.73 | 1.25 | .43 | .62 |
| MAXIMUM ANCHORAGE FORCE | T(plf) | 820 | 1440 | 1870 | 742 | 1190 | 756 | 1220 | 1155 | 1030 | 1417 |
| | Ratio* | .57 | 1.0 | 1.30 | .52 | .83 | .53 | .85 | .80 | .72 | .98 |

*RATIO OF FORCE COMPONENT DIVIDED BY THAT OF ANSI-82

Figure 6. Design example 1: comparison of gross design loads.

and end frames). For exposure C, UBC-82 predicts a value 24 percent higher than ANSI-82 using method 1, and 74 percent higher by method 2 (due to the presence of loading on the horizontally projected area above the eave). The largest tie-down force T is specified by ANSI-82. This value is greater than that predicted by the other codes due to the inclusion of the internal pressure coefficient $C_{pi} = 0.25$ specified by this standard for single-story buildings.

#### Component and Cladding Loads

Figures 7 and 8 provide a comparison of the design loads (psf) for assumed tributary areas of 5 and 125 sq ft, which are typical of the areas influencing the design of the fasteners and structural components, respectively, for a building of this type. It should be noted that the building surfaces have been "zoned" in accordance with the provisions of ANSI-82 and MBMA-81. UBC-82 provides slightly different zoning methods; UBC-79 does not specifically address the question of loads to be used in the design of "components and cladding" (presumably they are the same as for the "main wind-force resisting systems").

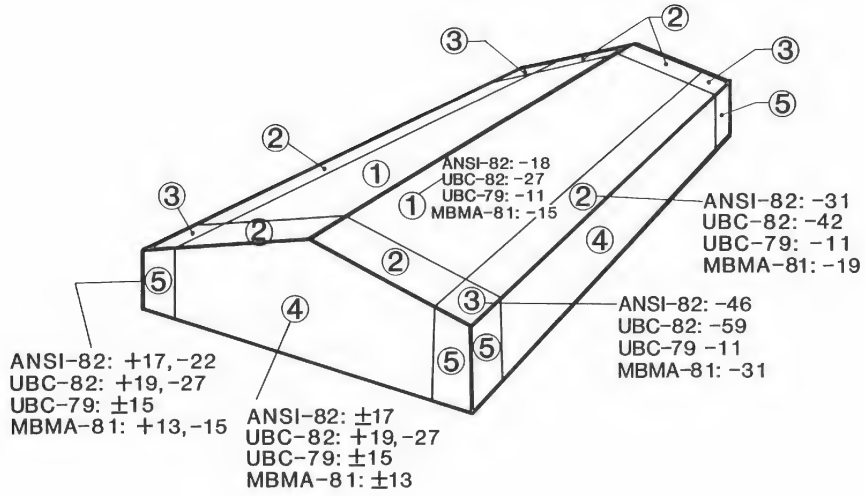



Figure 7. Component and cladding loads (psf) for tributary area of 5 sq ft.

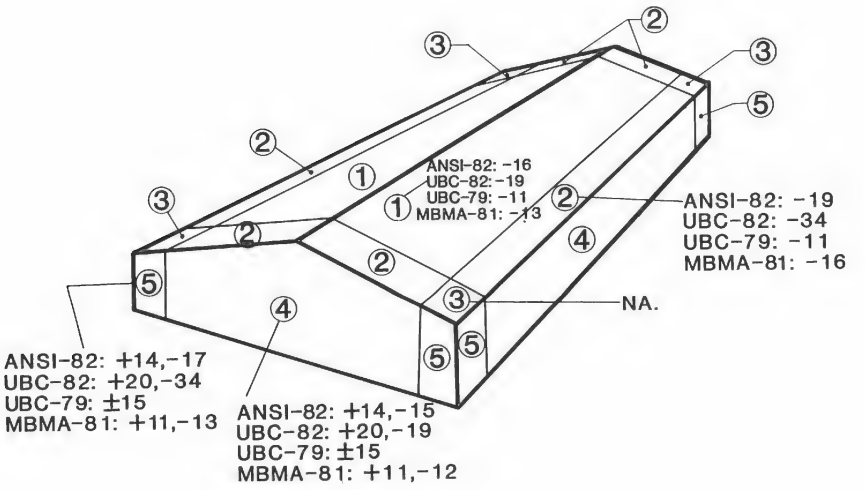



Figure 8. Component and cladding loads (psf) for tributary area of 125 sq ft.

The largest variation in design loads specified is seen to occur for a tributary area of 5 sq ft (Figure 7). As anticipated, these extreme differences occur at the corners of the building (zone 3). The proposed revision of the Uniform Building Code (UBC-82) predicts a fastener loading 436 percent higher than the earlier

version (UBC-79) and 28 percent higher than ANSI-82. Substantially smaller differences in loads are shown in Figure 8 for an assumed tributary area of 125 sq ft (component loading). The largest variation is seen to occur along the eave (zone 2) where UBC-82 specifies a value of 34 psf as compared to a low of 16 psf for MBMA-81; ANSI-81 requires 19 psf. The largest variation would occur in zone 3 but this has not been shown, as for the building considered, the length of this zone is only 8 ft and hence would not appreciably influence the design of a purlin.

#### Conclusions

It has long been recognized that the wind load design provisions of the old Uniform Building Code (UBC-79) represented an oversimplification of a very complex problem. For the design example presented, the loads applicable for the design of the "main wind-force resisting systems" have been shown to be generally conservative as compared to the other codes and standards considered. It has been demonstrated, however, that for "component and cladding" loads the opposite is true. Design pressures adjacent to the geometric discontinuities of the building may be as much as 500 percent higher than those prescribed by UBC-79. It is worthy of note, that historically, the largest percentage of costs due to severe wind events can be attributed to localized failures of cladding or secondary structural components. The proposed revision of this code (UBC-82) has attempted to resolve this problem, although the predicted loads appear to be somewhat on the conservative side for low-rise buildings.

In the future as code provisions are tailored for specific classes of buildings (in terms of gross geometry, framing considerations, etc.), more rational approaches will evolve. The end result should be lower design loads, but somewhat more sophisticated design procedures. The wind load provisions of the industrial standard MBMA-81 afford an excellent example of what, hopefully, will be the trend in the future in attempting to codify wind effects. The question of using the 80 percentile of maximum values measured in the wind tunnel for components and cladding design is, as yet, a point of controversy. Undoubtedly, as the profession moves toward Load and Resistance Factor Design (LRFD), different risk levels will be assigned for components and cladding as compared to the design of the main wind-resisting systems and this question will finally be resolved.

#### Acknowledgments

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# Rodent-Vegetation Relationships in Southeastern Montana

**Abstract**

Plant communities of southeastern Montana were surveyed for rodents over a two year period. Deer mice (*Peromyscus maniculatus*) were the most abundant rodent species found on the study area. Prairie voles (*Microtus ochrogaster*), meadow voles (*M. pennsylvanicus*), sagebrush voles (*Lagurus curtatus*), Wyoming pocket mice (*Perognathus fasciatus*), thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*), least chipmunks (*Eutamias minimus*), and eastern fox squirrels (*Sciurus niger*) also were captured. Grassland, riparian, and sagebrush communities showed the greatest rodent abundance and species diversity. There was a significant positive relationship between rodent abundance and the cover provided by some understory plant species and tree density on the study area.

## Introduction

Small mammals are important components of most natural ecosystems in North America. Dusek and McCann (1973) considered some of the aesthetic, recreational, and ecological values of deer mice (*Peromyscus maniculatus*) that also apply to many other rodent species. McCann (1974) stressed the need for more information on rodent ecology in Montana.

Investigators have inferred from their data that microhabitat features such as vegetation structure, cover and height, relative humidity, litter depth, and foliage height diversity, are important plant community variables affecting rodent abundance (M'Closkey and Fieldwick 1975, Birney *et al.* 1976, Kirkland 1976, Holbrook 1978, Carroll and Genoways 1980). These features are directly related to the life form and growth pattern of specific plant species within a plant community.

This paper presents estimates of relative abundance and population size of small mammals in relation to plant cover in southeastern Montana.

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### Study Area

The study area of approximately 11,300 ha was located immediately west of the town of Alzada, Carter County, in extreme southeastern Montana. Elevations ranged from 1040 to 1130 m and annual precipitation averaged 37 cm. A majority of the area (74 percent) was dominated by sagebrush-grass vegetation associations. The most abundant plants were big sagebrush (*Artemisia tridentata*) and buffalograss (*Buchloe dactyloides*). Riparian areas, primarily wooded stream bottoms, were the next most prevalent type (14 percent), composed of green ash (*Fraxinus pennsylvanicus*) and snowberry (*Symphoricarpos* sp.). Pine forests, on 8 percent of the study area, occupied higher elevations. Major plants in this forest were ponderosa pine (*Pinus ponderosa*) and western wheatgrass (*Agropyron smithii*). Grassland areas covered the least amount of land (0.2 percent) and were composed of western wheatgrass and neddleleaf sedge (*Carex eleocharis*). The remainder of the study area (3.8 percent) was classified as land disturbed by bentonite mining. Plant names follow those given by Scott and Wasser (1980).

Cattle and sheep were managed on a rest-rotation grazing system on the study area.

### Methods

In both the riparian and sagebrush communities four sampling sites were selected. Two sites each were studied in pine forest and grassland communities. Sites were selected as representative of the variability within a plant community. The number of replications established in a plant community were based on that variability and land area occupied.

Each site was surveyed for small mammals with two trap lines approximately 61 m apart. Each line consisted of a total of 20 Sherman live traps ( 9 X 8 X 23 cm) being spaced at 10 m intervals. Rodents were trapped during the second week of each month from April through October during 1979 and 1980. A mixture of rolled oats, bird seed, and peanut butter was used as bait. Traps were prebaited for one night, then opened for the following three nights. Traps were exposed 6720 and 3360 trap nights in sagebrush and riparian communities and in pine forest and grassland communities, respectively. Captured rodents were identified as to species, weighed, marked, and released.

Relative abundance of rodents was estimated as the total number of a species captured, including recaptures, per 100 trap nights. Abundance figures were averaged across consecutive months to provide seasonal estimates. April through June comprised the spring season, July and August summer, and September and October fall. Comparisons in rodent abundance among seasons were made.

Rodent population size was estimated using the CAPTURE computer program as described by Otis *et al.* (1978). Estimates were made for each species, for each year, and plant community if sufficient data were available. We chose one model to estimate population size based on the initial results and tests for population closure.

Percent canopy cover of understory plant species was determined at each trapping site using methods described by Daubenmire (1959). At each set of trap lines, three 50 m line transects were established approximately 30.5 m apart and

parallel to the trap lines. Canopy coverage class of each plant species was estimated in 50 two by five dm plots systematically spaced every meter along each transect line. Tree densities were estimated by counting all trees within a 50 x 50 m plot at each trapping site.

Differences in relative abundance of the three most abundant small mammals were analyzed with factorial analysis of variance for significance between years, seasons, plant communities, and species. Tukey's method was used to determine which factors produced differences. Product-moment correlation compared rodent abundance and canopy cover of plants, litter, and bare ground, as well as tree densities. For each year of study, plant community parameters were stable whereas rodent captures fluctuated monthly. Differences were considered significant at the 5 percent level of probability.

#### Results

Rodents captured, in decreasing order of abundance, were, deer mice, meadow voles (*Microtus pennsylvanicus*), thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*), least chipmunks (*Eutamias minimus*), prairie voles (*M. ochrogaster*), Wyoming pocket mice (*Perognathus fasciatus*), sagebrush voles (*Lagurus curtatus*), and eastern fox squirrels (*Sciurus niger*) (Table 1).

Three categories of rodent abundance were examined: year, season, and plant community. Total populations were higher in 1979 than 1980. Deer mouse abundance was greater ($P < 0.01$) in 1979 than 1980 in grasslands during spring, in pine and sagebrush habitats during summer, and in riparian habitat during all seasons. *Microtus* spp. and *Lagurus curtatus* were not captured in 1980. No other species exhibited significant differences in abundance between years.

Only deer mouse abundance exhibited significant seasonal differences, and only during 1979 (Table 1). Deer mice were most abundant during spring, less so in summer, and least in fall.

Rodent abundance was generally higher in grassland and riparian communities, but seasonal differences were noted. Again, only deer mice exhibited significant differences in relative abundance between community types, and only during 1979 (Table 1).

Deer mice and voles (*Microtus* spp.) were the most abundant rodents in 1979 in most plant communities. During 1980, deer mice and thirteen-lined ground squirrels were most abundant (Table 1). No differences in abundance ($P > 0.05$) were evident among rodent species captured in 1980 (Table 1).

Rodent population size was estimated using the model for heterogeneous trapping probabilities among individuals (Table 2). Population estimates could be derived for deer mice, voles, and ground squirrels for 1979; however, only deer mice populations could be estimated in 1980.

Rodent populations were greatest in riparian habitat during both years. Rodent population estimates were greatest for all plant communities during 1979. Deer mice were the most abundant rodent in any habitat based on population estimates (Table 2). Generally, estimated population size closely followed trends in relative abundance. The test for closure was significant ($P < 0.03$) in all cases. The model for capture probability varying among individuals fit the data best and was used for all population estimates (Table 2). However, in a few cases, the

TABLE 1. Mean ( ± SE) relative abundance (numbers/100 trap nights) of rodents on a seasonal basis during 2 years of study in 4 plant communities of southeastern Montana.

| Community and Species | Season | | | | | |
|---|---|---|---|---|---|---|
| | Spring | | Summer | | Fall | |
| | 1979 | 1980 | 1979 | 1980 | 1979 | 1980 |
| Grassland | | | | | | |
| *Peromyscus maniculatus* | 11.3 ± 3.8 | 3.3 ± 1.2 | 5.4 ± 1.2 | 2.1 ± 1.8 | 5.8 ± 3.5 | 0.4 ± 0.4 |
| *Spermophilus tridecemlineatus* | 0.8 ± 0.8 | 0.8 ± 0.3 | 1.9 ± 1.7 | 0.4 ± 0.3 | 0.4 ± 0.2 | * |
| *Perognathus fasciatus* | | 0.4 ± 0.3 | 0.4 ± 0.3 | 0.4 ± 0.3 | | |
| *Lagurus curtatus* | | | 0.4 ± 0.3 | | | |
| Pine | | | | | | |
| *Peromyscus maniculatus* | 6.3 ± 0.3 | 2.9 ± 0.3 | 9.3 ± 0.9 | 2.5 ± 0.6 | 2.9 ± 0.9 | * |
| *Eutamias minimus* | | 0.8 ± 0.8 | 0.8 ± 0.8 | | 1.3 ± 1.2 | |
| *Perognathus fasciatus* | | | 0.2 ± 0.1 | | | |
| *Microtus ochrogaster* | | | 0.2 ± 0.1 | | | |
| *Lagurus curtatus* | | | | | | * |
| Riparian | | | | | | |
| *Peromyscus maniculatus* | 7.7 ± 2.5 | 2.7 ± 0.3 | 6.5 ± 2.1 | 0.7 ± 0.3 | 6.7 ± 1.2 | 0.4 ± 0.2 |
| *Microtus pennsylvanicus* | 1.9 ± 0.7 | | 3.1 ± 1.5 | | 1.5 ± 0.5 | |
| *Microtus ochrogaster* | | | 0.2 ± 0.2 | | | |
| *Spermophilus tridecemlineatus* | * | 0.2 ± 0.1 | 0.2 ± 0.2 | 0.2 ± 0 | | * |
| *Lagurus curtatus* | | | * | | | |
| *Perognathus fasciatus* | | * | | | | |
| *Sciurus niger* | | * | | | | |
| Sagebrush | | | | | | |
| *Peromyscus maniculatus* | 6.0 ± 1.8 | 2.9 ± 0.5 | 5.4 ± 1.4 | 1.3 ± 0.4 | 2.9 ± 0.8 | 0.8 ± 0.4 |
| *Spermophilus tridecemlineatus* | 0.2 ± 0.2 | 0.4 ± 0.2 | 0.4 ± 0.2 | 0.2 ± 0.2 | 0.4 ± 0.2 | * |
| *Perognathus fasciatus* | 0.2 ± 0.2 | 0.2 ± 0.1 | 0.2 ± 0.2 | * | 0.2 ± 0.1 | |
| *Microtus ochrogaster* | * | | 0.2 ± 0.2 | | * | |
| *Lagurus curtatus* | | | 0.2 ± 0.2 | | 0.4 ± 0.1 | |

* < 0.1

TABLE 2. Population estimates of some rodents ($\bar{x} \pm SE$) for four plant communities in southeastern Montana during 1979 and 1980.

| Year and Rodent Species | Plant Community | | | |
|---|---|---|---|---|
| | Grassland | Pine | Riparian | Sagebrush |
| **1979** | | | | |
| *Peromyscus maniculatus* | 128 ± 44 | 43 ± 2 | 138 ± 23 | 74 ± 13 |
| *Microtus pennsylvanicus* | | | 117 ± 41 | |
| *Spermophilus tridecemlineatus* | 12 ± 2 | | | |
| **1980** | | | | |
| *Peromyscus maniculatus* | 16 ± 6 | 25 ± 6 | 39 ± 7 | 37 ± 16 |

model for capture probability varying due to a behavioral response to capture, variation over time, and for probability of capture remaining constant, were significant.

Significant correlations ($P < 0.05$) among understory plant species canopy cover, and tree densities, with rodent abundance were detected. Only deer mice, voles and thirteen-lined ground squirrels were included in correlation analysis (Table 3).

Vole abundance was positively associated with cover of smooth brome (*Bromus inermis*), japanese brome (*B. japonicus*), common timothy (*Phleum pratense*), macoun's wildrye (*Elymus macouni*), bluegrasses (*Poa* spp.), and density of chokecherry (*Prunus virginianus*), green ash, and boxelder maple (*Acer negundo*). Snowberry cover was also significantly correlated with vole abundance.

Deer mouse distribution was positively related to cover of wheatgrasses, macoun's wildrye, japanese brome, and total cover, as well as to the density of peachleaf willow (*Salix amygdaloides*).

Significant correlations among thirteen-lined ground squirrel abundance and cover of western wheatgrass, bare ground, and plains prickly pear (*Opuntia polyacantha*) were observed (Table 3).

#### Discussion

This investigation indicates that some rodent species occupied only one or two plant communities, while others were found in a variety of communities throughout the study area. Other studies have shown the same thing (Zimmerman 1965, Geluso 1971, Stinson 1978, Feldhammer 1979, Stamp and Ohmart 1979). Necessary microhabit features are present within broad habitat types where rodents occur in southeastern Montana. Presumably plant species that are correlated with rodent abundance are an integral part of those microhabitats.

Correlations among rodent abundance and habitat features indicates the relative importance of cover provided by a relatively few plant species. Correlations were based on rodent and plant abundance over the entire study area, and are not limited to a specific plant community-rodent relationship. Correlations indicate that voles are associated with plant communities where grasses, shrubs, and trees are major

TABLE 3. Product moment correlations among understory plant species and bare ground canopy cover, tree densities, and rodent abundance in southeastern Montana. * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.0001$ at 146 d.f.

| | Rodents | | |
|---|---|---|---|
| | *Peromysus maniculatus* | *Spermophilus tridecemlineatus* | *Microtus* spp. |
| Bare ground | −0.06 | 0.42*** | −0.42 |
| Total cover | 0.34*** | −0.08 | 0.44*** |
| Grasses | | | |
| *Agropyron* spp. | 0.45*** | −0.09*** | 0.21* |
| *A. smithii* | 0.34*** | 0.37*** | −0.02*** |
| *Bromus inermis* | 0.04*** | −0.14 | 0.31*** |
| *B. japonicus* | 0.47*** | −0.06 | 0.27** |
| *Elymus macouni* | 0.35*** | −0.13 | 0.23** |
| *Phleum pratense* | 0.22** | −0.14 | 0.36*** |
| *Poa* spp. | 0.25** | −0.19* | 0.53*** |
| Shrubs | | | |
| *Artemisia tridentata* | 0.05 | 0.21* | 0.22** |
| *Symphoricarpos* spp. | 0.17* | −0.15 | 0.49*** |
| *Opuntia polyacantha* | 0.10 | 0.48*** | −0.21* |
| Trees | | | |
| *Acer negundo* | −0.06 | −0.16 | 0.48*** |
| *Fraxinus pennsylvanicus* | 0.04 | −0.23** | 0.50*** |
| *Prunus virginianus* | 0.001 | −0.14 | 0.37*** |
| *Salix amygdaloides* | 0.30*** | −0.01 | −0.05 |

features. Vole abundance was highest in riparian communities where grass, shrub, and tree abundance was great. Deer mice were also associated with areas of abundant grass cover, and peachleaf willow density was also a major habitat feature. Deer mice were abundant over the entire study area, but most abundant in riparian habitat where grass cover was greatest and peachleaf willow was present. Thirteen-lined ground squirrels were associated with grass cover as well as plains prickly pear, and bare ground. These ground squirrels were captured in every area except those occupied by pine communities. Ground squirrels, which were most abundant in sagebrush and grassland communities, were also captured in a riparian area that was in close juxtaposition to both a sagebrush and grassland community.

It should be noted that correlations do not necessarily represent cause and effect relationships. Rodents in southeastern Montana may occupy habitat based on features other than plant cover. These features may be correlated with plant abundance, as are seed production, insect populations, and moisture gradients. Nevertheless, cover provided by plants is one of many important habitat features.

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# Lichens of Chowder Ridge, Mt. Baker, Washington

**Abstract**

A preliminary list of the alpine and subalpine lichens of Chowder Ridge and vicinity, Mt. Baker, Washington is presented, with notes on the habitats, relative cover and frequency of selected taxa. Of the approximately 200 taxa identified to species in this report, 80 are newly recorded for the North Cascade Mountains, and 45 of these are new for the State of Washington. Three are new to North America: *Aspicilia nordlandica* (Magn.) Degel., *Lecanora bicincta* Ram., and *Leciophysma finmarckicum* Th. Fr.

## Introduction

Lichens, which contribute to the formation, stabilization and nutrient-enrichment of soil, are often abundant enough in alpine habitats to be major components of the vegetation. Knowledge of the lichens is therefore useful in understanding the ecology of high mountain areas.

The alpine lichens of Washington State are poorly known. Only the macrolichens (foliose and fruticose taxa) were included in the keys of Imshaug (1957) for western North America, and those keys are incomplete and outdated. Ecological notes on the conspicuous lichens on soil were given by Milleren (1983) and Kunze (1980) for an area in the Olympic Mountains, and by Douglas and Bliss (1977) for the North Cascades.

The Chowder Ridge area, located in the North Cascades immediately northwest of Mt. Baker, has been proposed as a Research Natural Area for a number of reasons (Taylor and Douglas 1978). The only previous reports on the lichens of this area (mostly Skyline Divide) were brief mentions by Herre (1943) and Douglas (1974), and some ecological data given by Gilleland (1980) on common species on solifluction lobes. The first extensive collections of lichens from the site were Fred Rhoades' 1978 collections, which formed part of the basis for the present report.

The purpose of the present study was to make a preliminary list of the lichens occurring in the Chowder Ridge area, and to give a rough idea of the distribution, relative frequency, and cover of the common or conspicuous taxa at the site.

## Study Site

A map of the Chowder Ridge area is given in Figure 1. The major features of the site were described by Taylor and Douglas (1978). Habitats for lichens varied from protected subalpine forests (below about 1700 m) to areas that were fairly open but often moist or with late snowmelt (on north- or east-facing slopes, 1700-1900 m) to dry, often windy, relatively snow-free areas (on ridgetops and south- or west-facing slopes, 1900-2300 m).

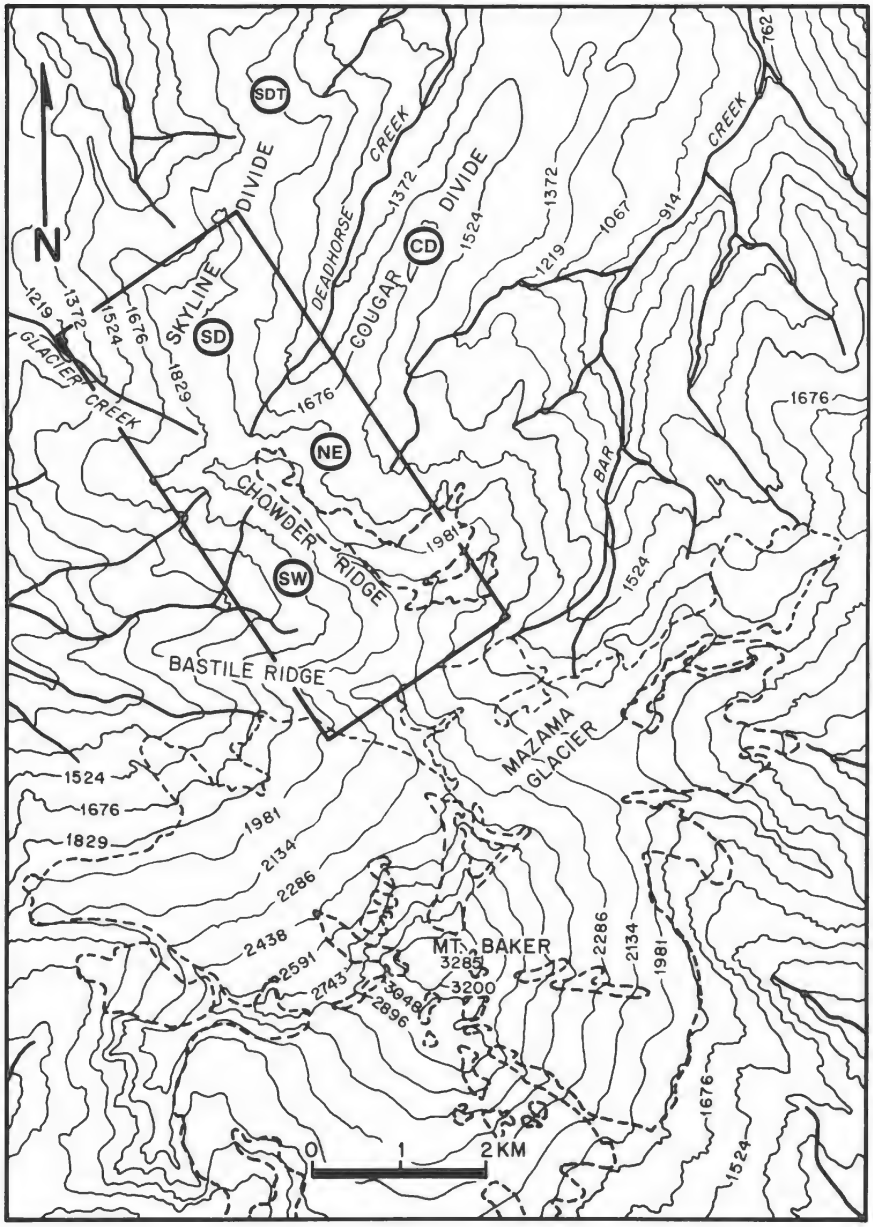


Figure 1. Map of Chowder Ridge and Mt. Baker, Whatcom County, Washington. Elevation is given in meters with topographic lines separated by about 152 m (500 ft). The area enclosed within the rectangle is the research natural area proposed by Taylor and Douglas (1978). The circled letters indicate collecting areas cited in present paper. Modified from Taylor and Douglas (1978).

Various types of bark and wood were substrates for lichens. Firs (*Abies* spp.) and hemlock (*Tsuga mertensiana*) dominated the forests and krumholz clumps. Juniper (*Juniperus occidentalis*), heathers (species of *Cassiope* and *Phyllodoce*), huckleberries (*Vaccinium* spp.), and a cinquefoil (*Potentilla fruticosa*) were also important.

Soil or humus, mosses (especially *Grimmia* spp.), and the spike moss *Selaginella densa* were often covered by lichens. The various vascular plant communities described by Taylor and Douglas (1978) provided different microhabitats for lichens on the ground; the dwarf shrub (*Cassiope/Phyllodoce/Vaccinium*) types were especially rich. Solifluction lobes, clumps of krumholz trees, and rock crevices each offered special habitats.

Rock types varied from smooth and soft, often fossiliferous siltstone (sometimes weakly HCl + ), to harder and rougher rocks of volcanic origin. Some outcrops were rich in iron oxides. A natural archway in a large outcrop on NE (1775 m—see Figure 1), talus slopes, and streambeds each provided special conditions.

#### Methods

Five trips to Chowder Ridge via Cougar Divide and two to Skyline Divide were made by the author in 1982 and 1983. Collections or observations were made in five areas of the site, abbreviated in the text and in Figure 1 as follows: CD = Cougar Divide Ridgetop (1300-1700 m), NE = northeast slope of Chowder Ridge (1700-1900 m), SW = Chowder Ridge summit and southwest of it (1900-2300 m), SD = north/central Skyline Divide (1700-2100 m), and SDT = Skyline Divide Trail (1300-1700 m). Information on subalpine lichens was gathered on CD and SDT.

An attempt was made to examine as many different substrates and microhabitats as possible, but no specific system of sampling was used. For most of the common or conspicuous taxa, subjective notes were made in the field about their relative frequency, cover and ecological distribution, and photographs were taken to help describe habitats or species groupings. For these taxa and the less common or less distinctive ones, the substrate, general area of the site (NE, SW, etc.) and elevation (estimated from map) were recorded on the collecting packet and used in describing distribution patterns.

Voucher specimens have been deposited in the herbarium of Western Washington University (WWB); duplicates of most species have been retained in the author's own collection. Duplicates of many taxa were given to R. Anderson (University of Denver), T. Esslinger (NDA), M. Hale (US), H. Hertel (M), J. Sheard (SASK) and J. Thomson (WIS) for identification, and have been placed in those herbaria.

#### Results and Discussion—Ecology and Distribution

A list of lichens from the site is given on pp. 285-292. More detailed notes on individual taxa are available from the author on request. The ecology and distribution of common or conspicuous taxa are described below according to major habitat type (alpine or subalpine), substrate type, and microhabitat.

## Subalpine Zone

Compared to the alpine, relatively few species of lichens occurred in the subalpine zone at the site; most are widely distributed boreal or temperate species typical of subalpine or montane areas throughout much of western Washington.

*Bark and Wood.* Approximately 35 species of lichens occurred on bark or wood in the subalpine area on CD and SDT. Most of these occurred on *Abies* spp. in the forests. Two species, *Alectoria sarmentosa* and *Mycoblastus alpinus,* were very frequent with high cover in the forests but rare in the alpine area. At least 12 other, less common taxa also appeared to be restricted to the forests. The remainder of the lichens in the forests were about equally common in the alpine area and are discussed under that heading. One lichen, *Cetraria subalpina,* was very abundant on the twigs of *Phyllodoce* and other shrubs in open subalpine areas. Several taxa were common on fairly rotten wood in a few areas: *Cladonia coniocraea* (strictly subalpine at this site), *C. carneola, Trapeliopsis granulosa* and *Xylographa hians.*

*Soil, Moss, Vegetable Matter.* Approximately 15 taxa of lichens occurred on the ground in the subalpine areas. Several unidentified taxa in the genus *Lepraria* were abundant on soil or moss in the forests but rare in the alpine and the open subalpine areas. Most of the other lichens on the ground occurred in the dwarf shrub (*Phyllodoce*) communities. The most common taxa were also common in the alpine zone: *Cladonia* spp., *Trapeliopsis granulosa, Lepraria neglecta, Peltigera canina* and *P. rufescens.* A few primarily alpine species such as *Solorina crocea* also occurred occasionally in the subalpine areas.

*Rock.* Because the most common saxicolous species occurred in the alpine areas, a comprehensive description of lichens on subalpine rocks is not given. Except for *Huillia crustulata*, few lichens were present on rock in the forests. In open areas with early snowmelt, a number of crustose lichens were abundant on the larger rocks. These included *Aspicilia* spp. (*A. gibbosa* group and *A. alpina* group), *Lecanora polytropa, Lecidea* spp. (especially the *L. atrobrunnea* group and various grey or cryptothalline taxa) and *Rhizocarpon spp. (mostly the R. geographicum* complex). One macrolichen, *Parmelia saxatilis,* was also common in some areas. The subalpine talus slopes were mostly barren except for occasional *Lecanora polytropa* or *Staurothele fuscocuprea.* Small rocks among *Phyllodoce* in flat, late snowmelt areas in the high subalpine/low alpine zone were often completely dominated by *Bacidia nivalis,* which seemed to be restricted to such habitats.

## Alpine Area

Approximately half of the nearly 200 lichen species identified from the alpine area of the site are typical of arctic/alpine areas in the northern hemisphere. The rest are mostly boreal or temperate species with wide ecological and geographical distributions. The lichen floras on the three substrate types partially overlapped.

*Bark and Wood.* Over 35 species of lichens occurred on bark or wood in the alpine area. About a third of these are primarily saxicolous or terricolous taxa. Most of the corticolous and lignicolous lichens occurred on krumholz *Abies lasiocarpa* and were also common in the subalpine area. The most common taxa on

krumholz were *Bryoria* spp., *Hypogymnia* spp. (especially *H. imshaugii*), *Lecanora coilocarpa auct., Lecidea nylanderi* and *Parmeliopsis hyperopta.* Several of the rarer lichens on krumholz appeared to be restricted to the alpine area at this site: *Candelariella lutella, Cetraria sepincola, C. platyphylla, Ochrolechia androgyna,* and the primarily saxicolous or terricolous taxa.

The lichen flora on *Juniperus* was similar to that on *Abies* but not as species rich. Most of the species on *Phyllodoce, Potentilla* and *Vaccinium* were primarily terricolous, strictly alpine taxa, except for *Cetraria subalpina* which extended up only into the lower part of the alpine zone. A few lichens, namely *Cladonia carneola, C. sulphurina* and *Xylographa hians,* occurred mainly on rotten wood on the ground.

*Soil, Moss Vegetable Matter.* At least 80 species of lichens occurred on the ground in the alpine zone. The distributions of these species are described below according to the habitats or vascular plant communities the lichens inhabited, arranged roughly along a gradient from those in moist areas with late snowmelt and high humus content to those in dry, rocky areas with early snowmelt.

On the moist end of the gradient, relatively few lichens occurred. Only a few lichens, such as *Cetraria islandica, Cladonia* spp. and *Lepraria neglecta auct.* occurred in moist meadows, and these taxa were much more abundant in somewhat drier areas. However, a few taxa, especially *Cladina rangiferina* and *Lepraria* spp. other than *L. neglecta,* were essentially restricted to areas sheltered by trees.

The greatest species richness and highest cover of lichens on the ground was in the dwarf shrub communities (*Cassiope/Phyllodoce/Vaccinium*). In general the dominant macrolichens in these communities were *Cetraria islandica, Cladina mitis, Cladonia* spp. (especially *C. ecmocyna*), *Peltigera* spp. (especially *P. malacea*) and *Stereocaulon* spp. At the edges of heather hummocks *Solorina crocea* was often abundant. *Cetraria nivalis* occurred only occasionally but was conspicuous. *Thamnolia vermicularis* was frequent but low in cover. Among the crustose lichens, *Lepraria neglecta auct.* was the most abundant and conspicuous, but *Lecidella wulfenii, Parmeliella praetermissa, Psoroma hypnorum* and species of *Buellia, Caloplaca, Lecanora, Lecidea* and *Rinodina* were very frequent, especially on moss. Some lichens, such as *Lecidoma demissum,* occurred mainly on patches of fairly barren soil between the shrubs. The lichen flora in the dwarf shrub communities on the ridgetops appeared to be fairly similar to that in the moist, late snowmelt areas.

Most of the lichens that were common on soil or moss among dwarf shrubs were also frequent on those substrates in the dry graminoid communities (*Carex spectabilis*) on SW, but they often had lower cover in the latter.

The macrolichen flora on solifluction lobes on SW and SD was described in some detail by Gilleland (1980), whose data showed that most of the lichens occurred mainly on the flatter, relatively snow-free parts ("treads"). Some of the dominant lichens, e.g. *Cladina mitis* and the *Cladonia gracilis* complex (mostly *C. ecmocyna*) had higher prominence values on the solifluction lobes than those given for *Phyllodoce* communities in the North Cascades by Douglas and Bliss (1977), while others such as *Cetraria islandica, Cladonia bellidiflora,* and *Thamnolia vermicularis* had lower values. To Gilleland's observations it may be added that

two lichen taxa appeared to be much more common on solifluction lobes than elsewhere at the site: *Peltigera spuria* (in dry graminoid meadows) and *Lobaria linita* (in dwarf shrub areas).

Several lichens occurred on soil in areas that were moist but rocky: *Collema* sp. (in crevices of rock outcrops on SW) and *Solorina crocea* (sometimes among moist rocks on SD).

Patches of soil, moss, or vegetable matter in dry rocky areas (e.g. vegetation stripes, fellfields, and rock outcrops, especially on the ridgetops) were often partly covered by *Cladonia* spp. (mostly basal squamules), *Melanelia elegantula, Ochrolechia upsaliensis, Parmelia* spp., *Peltigera rufescens, Stereocaulon* spp., *Thamnolia vermicularis,* and many less conspicuous lichens.

*Rock.* Over 100 species of lichens occurred on alpine rocks. The highest species richness and cover, especially for macrolichens, was on siltstone. However, many taxa appeared to be equally common on all rock types. No definite indicators of calcareous rock were apparent. The lichens can be arranged roughly along a gradient from those in moist, shaded or late snowmelt areas to those on dry, exposed ridgetops.

The aquatic lichens were the most distinct grouping. In one stream (1700-1850 m on NE), *Verrucaria elaeomelaena* and *V. margacea* co-dominated. In two streams on SD (about 1850 m), *Dermatocarpon rivulorum* and *Staurothele* spp. dominated.

Very shaded areas usually had few lichens, with low cover. *Acarospora oxytona* was very abundant on the shaded west face of the natural arch (NE) but rare elsewhere at the site. Some taxa, e.g. *Huillia crustulata,* occurred sometimes on stones under shrubs.

In areas that were less shaded but had late snowmelt, the larger rocks were sometimes dominated by *Umbillicaria cylindrica,* but more often by various crustose taxa. *Tremolechia atrata* was common on iron-rich outcrops. Species of *Aspicilia* (mainly the *A. alpina* group and *A. subsorediza*), *Lecidea* (mainly the *L. atrobrunnea* group and *L. leucothallina*), and *Rhizocarpon* (the *R. geographicum* group, *R. obscuratum*, and *R. polycarpum*) covered large areas on outcrops and were also frequent on small stones, along with *Lecanora polytropa,* which was low in cover.

Talus slopes in late snowmelt areas were often bare except for *Staurothele fuscocuprea,* which was frequent but low in cover. Volcanic rocks (mostly small stones) amidst heather in flat areas of the low alpine were often covered by *Bacidia nivalis.*

The larger, more stable rocks on the relatively snow-free ridgetops (SW and parts of NE and SD) usually had a rich flora. The dominant macrolichens were most often *Cetraria hepatizon, Pseudephebe* spp., and *Umbillicaria* spp. (mainly *U. proboscidea* and *U. hyperborea*). In some areas (more nutrient-rich?) species of *Parmelia sensu lato* and *Physcia sensu lato* were also abundant. On steep slopes *Xanthoria elegans* was sometimes the only abundant macrolichen. On more-or-less horizontal surfaces, *Alectoria* spp. and *Bryoria cf. subdivergens* were often important. *Cornicularia normoerica* was restricted to the most exposed, windy areas on the crest of SW. *Hypogymnia oroarctica* occurred mainly on the ridgetops. The placodioid taxa *Aspicilia alphoplaca, Lecanora cf. muralis,* and

*Rhizoplaca melanopthalma* were also conspicuous in some areas. The crustose taxa that were most characteristic of the ridgetops and often had the highest cover were *Aspicilia cf. mastrucata,* the *Lecanora rupicola* group, and *Sporostatia testudinea.* These species were usually mixed with others such as *Lecanora polytropa* and *Rhizocarpon geographicum,* which were also common in the late snowmelt areas. Several other crustose lichens, e.g. *Haematomma lapponicum* and *Lecidea armeniaca,* were conspicuous and restricted to the ridgetops, but they were rare. A number of others occurred mainly on the ridgetops and were high in frequency but low in cover: *Acarospora fuscata, Candelariella cf. vitellina, Lecanora cf. hageni, L. melaena,* the *Lecidea lapicida* group, and *Rhizocarpon disporum.* Most taxa that were common on the large rocks also occurred, with low cover, on small loose rocks in fellfields and vegetation stripes (SW).

#### Results and Discussion—Floristics

A preliminary list of lichens from the Chowder Ridge area is given below. Comments on variability or taxonomic problems are restricted to common or conspicuous taxa. About 200 taxa, in 75 genera, are listed. This is probably about two-thirds of the total number of species at the site. A number of taxa, including some that were common, have not yet been identified to species. This is especially true of sterile crustose lichens and members of large and poorly understood genera such as *Acarospora, Aspicilia, Lecanora,* and *Lecidea.* Many taxa were very inconspicuous or difficult to distinguish in the field, and were represented by fragmentary collections. Larger areas of the site (especially the lower elevations on SW) remain to be explored.

Of the identified species, 80 are newly recorded for the North Cascades; of these, 45 are new for Washington State, and 3 are new for North America. New records are indicated by asterisks in front of the name: * = North Cascades, ** = Washington State, and *** = North America. In the absence of monographic treatments, many lichens cannot be determined with complete certainty. Therefore in this paper *cf.* is used to indicate a degree of uncertainty.

Most newly recorded taxa were very common at the site (and often at other alpine sites in the North Cascades). Several of them have been previously collected by other workers in the same geographical areas but were not reported (or were reported as other species). There have been too few detailed reports on alpine lichens in the Pacific Northwest to draw definite conclusions about biogeographical patterns. The apparent richness of the lichen flora at the present site may be due partly to the lack of comparable studies and partly to the unusual rock type at the site.

*Acarospora* Mass.

*A. fuscata* (Schrad.) Arn.—On rock, SW.

**A. oxytona* (Ach.) Mass.—On rock, NE.

*A. cf. smaragdula*—On rock, NE, SW, SD; several varieties, all with thallus K-.

*Alectoria* Ach.

**A. lata* (Tayl.) Linds.—On bark or wood (*Abies, Phyllodoce, Potentilla*), NE, SW, SD; on rock, SW.

*A. nigricans* (Ach.) Nyl.—On rock, SW; rarely on bark, NE.

*A. sarmentosa* (Ach.) Ach. ssp. *sarmentosa*—On bark (*Abies, Tsuga*), CD, NE, SDT, and rarely SD.

*Allantoparmelia* (Vain.) Essl.

*A. alpicola* (Th. Fr.) Essl.—On rock, SW.

*Arthonia* Ach. *nom. cons.*

**A.* sp.—On rock, SW.

*Aspicilia* Mass.

**A. alphoplaca* (Wahlenb. *ex* Ach.) Poelt & Leuck.—On rock, SW.

*A. alpina* (Somm.) Arn.—On rock, NE, SW, SD; rather variable.

***A. cf. americana*—On rock, NE.

*A. cinereorufescens sensu lato*—On rock, CD, NE, SW, SD; including one form with brown, shiny thallus.

**A. cf. contorta*—On rock, SW.

***A. cf. mastrucata*—On rock, SW; rather variable; often sterile.

****A. nordlandica* (Magn.) Degel.—On rock, SW.

***A. subsorediza* (Lynge) R. Sant. *in* Vezda—On rock, NE, SW, SD.

*Bacidia* De Not.

*B. nivalis* Follm.—On rock, CD, NE.

*Baeomyces* Pers.

*B. rufus* (Huds.) Rebent.—On soil, NE, SD; poorly formed.

*Bryonora* Poelt.

***B. cf. castanea*—On soil or moss, NE, SW; spores rather large.

*Bryoria* Brodo & Hawksw.

*B. cf. abbreviata*—On wood (*Abies, Potentilla*), NE, SW; sterile, with long slender branches and few spinules.

*B. capillaris* (Ach.) Brodo & Hawksw.—On bark (*Abies*), CD.

*B. cf. chalybeiformis*—On bark (*Abies, Tsuga*), NE; on rock, SW; non-sorediate.

*B. fremontii* (Tuck.) Brodo & Hawksw.—On bark (*Abies, Tsuga*), CD, NE, SD, SDT; one form brittle, with fairly dull surface, thick cortex, and numerous pycnidia.

*B. fuscescens* (Gyeln.) Brodo & Hawksw.—On bark (*Abies*), CD, NE; including v. *positiva* (Gyeln.) Hawksw.

*B. glabra* (Mot.) Brodo & Hawksw.—On bark (*Abies, Tsuga*), CD, NE, SD, SDT.

***B. cf. subdivergens*—On rock, SW.

*Buellia* De Not.

***B. cf. aethalea*—On rock, NE, SW; thallus K-.

**B. geophila* (Flörke *ex* Somm.) Lynge—On moss and vegetable matter (*Cassiope, Selaginella*), NE, SW.

*B. papillata* (Somm.) Tuck.—On moss, NE, SW.

**B. verruculosa* (Sm.) Mudd—On rock, SW.

*Calicium* Pers.

**C. glaucellum* Ach.—On wood, SDT.

*Caloplaca* Th. Fr. *nom. cons.*

***C. cf. exsecuta*—On soil, NE, SW; disks red-black.

***C. festiva* (Ach.) Zw.—On rock, NE, SD.

*C. jungermanniae* (Vahl) Th. Fr.—On moss, rarely on wood, NE, SW; apothecia varying from yellow-olive to red-orange.

**C. leucoraea* (Ach.) Branth.—On soil, NE, SD.

*C. stillicidiorum* (Vahl) Lynge—On moss, rarely on wood, SW.

*Candelariella* Müll. Arg.

***C. lutella* (Vain.) Räs.—On wood (*Abies*), NE.

*C. terrigena* Räs.—On soil or moss, NE, SW.

**C. cf. vitellina*—On rock, SD, SW; spores unusually small.

*Cetraria* Ach. *nom. cons.*

*C. hepatizon* (Ach.) Vain.—On rock, NE, SW, SD; rarely on wood, NE; lobes quite variable in width.

*C. islandica sensu lato*—On soil or moss, NE, SW, SD; quite variable in form and color; both P + red and P – strains (including report of *C. ericetorum* by Douglas, 1974).

*C. nivalis* (L.) Ach.—On soil, NE, SW.

*C. platyphylla* Tuck.—On wood (*Abies*), NE.

*C. sepincola* (Ehrh.) Ach.—On wood (*Abies, Juniperus*), NE.

*C. subalpina* Imsh.—On bark or wood (*Abies, Phyllodoce*), CD, NE, SD, SDT.

*Cladina* (Nyl.) Harm.

*C. mitis* (Sandst.) Hale & Culb.—On soil, NE, SW, SD.

*C. rangiferina* (L.) Harm.—On soil, SD.

*Cladonia* Hill *ex* Wigg.

*C. bellidiflora* (Ach.) Schaer.—On soil, CD, NE, SD.

*C. carneola* (Fr.) Fr.—On soil or rotten wood, NE, SD, SDT; reported by Gilleland (1980) as *C. pleurota.*

*C. coccifera* (L.) Willd.—On soil, NE, SD, SW.

*C. coniocraea* (Flörke) Spreng.—On rotten wood, CD, SDT.

*C. ecmocyna* (Ach.) Nyl.—On soil or moss, NE, SD; several varieties; reported by Gilleland (1980) as *C. gracilis.*

*C. fimbriata* (L.) Fr.—On soil, CD, NE, SD, SDT.

C. gracilis (L.) Willd.—On soil, NE, SW, SD; several varieties.

**C. macrophyllodes* Nyl.—On soil or moss, CD, NE, SW.

*C. pyxidata* (L. Harm.—On soil or moss, CD, NE, SW, SD.

*C. squamosa* (Scop.) Harm.

ssp. *squamosa*—On soil, SD (Douglas, 1974).

ssp. *subsquamosa* (Nyl.) Vain.—On soil, CD, NE, SD; reported by Gilleland (1980) as *C. furcata.*

*C. sulphurina* (Michx.) Fr.—On soil or rotten wood, NE, SD.

*Coelocaulon* Link

*C. cf. aculeatum*—On soil or rock, NE, SW, SD; rarely on wood (*Abies, Juniperus*), NE; some forms close to *C. muricatum.*

*Collema* Wigg. *nom. cons.*

*C. sp.*—On soil or rock, SW; isidiate; poorly formed, sterile.

*Coniocybe* Ach.

*C. furfuracea* (L.) Ach.—On soil under *Abies* stump, SDT.

*Cornicularia* (Schreb.) Hoffm.

*C. normoerica* (Gunn.) Du Rietz—On rock, SW.

*Dermatocarpon* Eschw. (including *Catapyrenium* Flot.)

**D. cf. lachneum*—On soil, NE.

*D. cf. reticulatum*—On soil or rock, NE, SW.

*D. rivulorum* (Arn.) DT. & Sarnth.—On rock, SD and rarely NE.

*Diplotomma* Flot.

*D. alboatrum* Hoffm.) Flot.—On rock, NE.

*Haematomma* Mass.

*H. lapponicum* Räs.—On rock, SW.

*Huillia* Zahlbr.

*H. cf. albocaerulescens*—On rock, NE, SD.

*H. crustulata* (Ach.) Hertel—On rock, CD, NE, SD, SDT.

*Hypogymnia* (Nyl.) W. Wats.

***H. bitteri* (Lynge) Ahti—On bark or wood (*Abies, Potentilla*), NE, SW; often poorly developed.

**H. imshaugii* Krog—On bark or wood (*Abies, Juniperus, Tsuga*), CD, NE, SD, SDT.

***H. oroarctica* Krog—On rock, SW and rarely NE.

***H. cf. rugosa*—On bark (*Abies*), SD.

*Ionaspis* Th. Fr.

***I. epulotica* (Ach.) Th. Fr.—On rock, NE, SW, SD; one form with dark bluish apothecia.

*Lecanora* Ach.

****L. bicincta* Ram.—On rock, NE, SW.

*L. cenisia* Ach.—On rock, NE.

*L. coilocarpa auct.*—On bark (*Abies, Juniperus, Tsuga*), CD, NE, SD, SDT; epithecium not granular.

*L. hageni sensu lato*
form #1—On rock, SW; apothecia red-brown, bare.
form #2—On soil, moss, vegetable matter (*Selaginella*) or wood (*Potentillia*); apothecia mostly tan and pruinose.

***L. intricata* (Ach.) Ach.—On rock, SW.

**L. melaena* (Hedl.) Fink—On rock, SW.

*L. cf. muralis*—On rock, CD, SD; thallus greenish to brown.

**L. novomexicana* Magn.—On rock, NE; *"L. thomsonii"* form.

*L. polytropa* (Ehrh.) Rabenh.—On rock, CD, NE, SW, SD; rarely on moss, NE; several varieties.

*L. rupicola* (L.) Zahlbr.—On rock, NE, SW.

*Lecidea* Ach.

**L. armeniaca* (DC.) Fr.—On rock, SW; one form with whitish thallus and weak K reaction, on NE.

***L. atromarginata* Magn.—On rock, NE, SW; hypothallus poorly developed; rather variable; report of *"L. elata"* from SD by Herre (1943) may have been based on this species.

*L. cf. atrobrunnea*—On rock, CD, NE, SD, SW; extremely variable; often with brownish hypothecium, small pale areoles and weak reaction with I; one form with norstictic acid in exciple but not thallus.

*L. fusca* (Schaer.) Th. Fr.—On soil, NE.

****L. *belvola*** (Körb.) Oliv.—On bark (*Abies*), CD.

****L. *impavida*** Th. Fr.—On rock, SW.

****L. *instrata*** Nyl.—On rock, NE, SW.

*L. lactea* Flörke *ex* Schaer.—On rock, NE,SW, SD; not listed for North Cascades by Douglas (1974) but reported from SD (as *L. pantherina*) by Herre (1943).

****L. *leucothallina*** Arn.—On rock, NE, SD; thallus K-, P-.

****L. *mannii*** Tuck.—On rock, NE.

****L. *nylanderi*** (Anzi) Th. Fr.—On bark (*Abies, Tsuga*), CD, NE, SD, SDT.

*L. tornoensis* Nyl.—On bark (*Abies, Juniperus*), NE.

****L. *cf. truckeei***—on rock, NE; thallus not pulvinate.

*L. uliginosa* (Schrad.) Arn.—On soil, NE, SD.

*Lecidella* Körb.

*L. cf. stigmatea*—On rock, SW.

***L. *wulfenii*** (Hepp) Körb.—On moss, vegetable matter, or wood (*Juniperus, Potentila*), NE, SW; thallus C-, KC-.

*Lecidoma* G. Schneid. & Hertel

*L. demissum* (Rutstr.) G Schneid. & Hertel—On soil, NE, SD, SW.

*Leciophysma* Th. Fr.

*****L. *finmarckicum*** Th. Fr.—On soil, NE.

*Lepraria* Ach. *nom. cons.*

*L. neglecta auct.*—On soil or moss, rarely rock or wood, CD, NE, SW, SD, SDT; granular thalli, matching *L. arctica sensu* Anderson (exsiccat no. 23).

*L. cf. incana*—On soil, moss, bark, wood or rock, CD, SD, SDT, NE, SW; farinose thalli, probably several taxa.

*Leprocaulon* Nyl. *ex* Lamy

***L. *subalbicans*** (Lamb) Lamb & Ward—On soil or moss, NE, SW.

*Leptogium* (Ach.) S. Gray

*L. lichenoides* (L.) Dicks.—On moss, NE, SW.

*L. tenuissimum* (Dicks.) Fr.—On moss, NE.

*Lobaria* (Schreb.) Hoffm.

*L. linita* (Ach.) Rabenh.—On soil or moss, NE, SW, SD.

*Lopadium* Korb. nom. cons.

*L. pezizoideum* (Ach.) Korb.—On bark (*Abies*) on CD and SDT; on vegetable matter, NE.

*Massalongia* Körb.

*M. carnosa* (Dicks.) Körb.—On moss, SD.

*Melanelia* Essl.

***M. *elegantula*** (Zahlbr.) Essl.—On soil, moss, or rock, NE, SD, SW; rather variable, often poorly developed.

*Microglaena* Korb.

****M. *cf. muscorum***—On moss, NE.

*Mycoblastus* Norm.

***M. *alpinus*** (Fr.) Kernst.—On bark or wood (*Abies, Tsuga*), CD, SDT and rarely SD.

*M. sanguinarius* (L.) Norm.—On bark (*Abies*), SDT.

*Nephroma* Ach.

*N. parile* (Ach.) Ach.—On soil or moss, NE, SD.

*Ochrolechia* Mass.

****O. androgyna*** (Hoffm.) Arn.—On bark or wood (*Abies*), NE.

****O. frigida*** (Sw.) Lynge—On moss, vegetable matter, or wood (*Juniperus*), NE, SD.

*O. oregonensis* Magn.—On bark (*Abies*), CD, SDT.

*O. cf. pallescens*—On bark (*Abies*), CD, SDT.

*O. upsaliensis* (L.) Mass.—On soil, moss, or vegetable matter (*Selaginella, Potentilla*), NE, SW, SD.

*Pannaria* Del.

***P. leucophaea*** (Vahl) P. Jorg.—On moss, SW, SD.

***P. pezizoides*** (Web.) Trev.—On moss, NE, SD.

*Pachyospora* Mass.

***P. verrucosa*** (Ach.) Mass.—On soil, moss or vegetable matter (*Potentilla*), SW.

*Parmelia* Ach.

*P. omphalodes* (L.) Ach.—On moss or rock, NE, SW, SD; poorly developed.

*P. saxatilis* (L.) Ach.—On rock, soil, or moss, CD, NE, SW, SD, and SDT.

*P. sulcata* Tayl.—On bark (*Abies*) SDT.

*Parmeliella* Müll. Arg.

*P. praetermissa* (Nyl.) P. James—On soil or moss, NE, SW.

*Parmeliopsis sensu lato*

*P. ambigua* (Wulf.) Nyl.—On bark (*Abies*), CD, NE.

*P. hyperopta* (Ach.) Arn.—On bark or wood (*Abies, Juniperus, Tsuga*), CD, NE, SD, SDT.

*Peltigera* Willd. *nom. cons.*

*P. canina* (L.) Willd.—On soil, SW, SD.

*P. lepidophora* (Nyl.) Vain.—On moss over rock, NE.

*P. leucophlebia* (Nyl.) Gyeln.—On soil, moss, or rock, NE, SW.

*P. malacea* (Ach.) Funck.—On soil or moss, NE, SW, SD.

*P. cf. polydactyla*—On soil or moss, NE, SD; sterile.

*P. rufescens* (Weis.) Mudd—On soil or rock, CD, NE, SW, SD, SDT.

***P. scabrosa*** Th. Fr.—On soil or moss, SD.

*P. spuria* (Ach.) DC.—On soil, SW and rarely NE.

*Pertusaria* DC. *nom. cons.*

***P. opthalmiza*** (Nyl.) Nyl.—On bark (*Abies*), SDT.

*Phaeophyscia* Moberg

****P. constipata*** (Norrl. & Nyl.) Moberg—On moss, NE.

***P. sciastra*** (Ach.) Moberg—On rock, rarely on moss, SW.

*Phaeorrhiza* Mayrh. & Poelt

****P. nimbosa*** (Fr.) Mayrh. & Poelt—On moss, SW.

*Physcia* (Schreb.) DC.

*P. cf. aipolia*—On rock, NE, SW; lobes very broad.

*P. caesia* (Hoffm.) Hampe—On rock, SW; rarely on moss, NE, SD; often poorly formed.

*P. dubia* (Hoffm.) Lett.—On rock, NE, SW, SD; variable, often poorly formed.

***P. cf. phaea***—On moss, NE; lobes pruinose above.

*Physconia* Poelt

*P. muscigena* (Ach.) Poelt—On moss, NE, SW.

*Placopsis* (Nyl.) Linds.

*P. gelida* (L.) Linds.—On rock, NE, SW; poorly developed.

*Placynthium* S. Gray

***P. asperellum* (Ach.) Trev.—On rock, SW.

*Platismatia* W. Culb. & C. Culb.

*P. glauca* (L.) W. Culb. & Culb.—On bark or wood (*Abies*), CD, NE, SDT.

*P. norvegica* (Lynge) W. Culb. & C. Culb.—On bark (*Abies*), SDT.

*Polychidium* (Ach.) S. Gray

**P. muscicola* (Sw.) S. Gray—On moss, SW.

*Protoblastenia* (Zahlbr.) Steiner

**P. cinnabarina* (Sommerf.) Räs.—On bark (*Abies*), CD, NE.

*Protoparmelia* Choisy

*P. badia* (Hoffm.) Haffelner—On rock, NE, SW.

*Pseudephebe* Choisy

*P. minuscula* (Nyl. *ex* Arn.) Brodo & Hawksw.—On rock, NE, SW.

*P. pubescens* (L.) Choisy—On rock, NE, SW, SD; rarely on wood (*Abies*), NE.

*Psora* Zahlbr. *emend.* G. Schneid.

***P. nipponica* (Zahlbr.) G. Schneid.—On soil or moss, SD, SW.

*P. rubiformis* (Wahlenb. *ex* Ach.) Hook.—On soil, NE, SW.

*Psoroma* (Ach.) Ach. *ex* Michx.

*P. hypnorum* (Vahl) S. Gray—On moss or vegetable matter (*Cassiope*), NE, SW, SD.

*Rhizocarpon* Ram. *ex* DC.

***R. copelandii* (Körb.) Th. Fr.—On rock, SW.

*R. disporum* (Naeg. *ex* Hepp) Müll. Arg.—On rock, SW.

*R. geographicum sensu lato*—On rock, CD, NE, SW, SD, SDT; quite variable.

***R. inarense* (Vain.) Vain.—On rock, CD, SW; form on SW with white (but UV+ yellow) thallus.

*R. obscuratum* (Ach.) Mass.—On rock, NE, SW.

***R. polycarpum* (Hepp) Th. Fr.—On rock, NE, SW, SD.

*R. riparium sensu lato*—On rock, NE, SD, SW; quite variable, often approaching the *R. lecanorinum* group in external form, but spores few-celled.

***R. simillium* (Anzi) Lett.—On rock, SW.

*Rhizoplaca* Zopf.

*R. chrysoleuca* (Sm.) Zopf.—On rock, NE.

*R. melanopthalma* (Ram.) Leuck.—On rock, NE, SW; sometimes poorly developed and non-umbillicate.

*Rinodina* (Ach.) S. Gray

***R. archaea* (Arn.) Arn. (Including *R. archaeoides* Magn.)—On wood (*Abies, Juniperus*), NE; on soil or moss, SW, rarely NE.

***R. roscida* (Somm.) Arn.—On moss or vegetable matter (*Potentilla*), SW.

***R. septentrionalis* Malme—On wood (*Juniperus, Potentilla*), NE, SW.

*Schaereria* Körb.

***S. tenebrosa* (Flot.) Hertel & Poelt—On rock, NE, SW.

*Solorina* Ach.

*S. crocea* (L.) Ach.—On soil or moss, NE, SW, SD, and rarely CD.

*Sphaerophorus* Pers. *nom. cons.*

*S. tuckermanii* Räs.—On bark (*Abies*), SDT.

*Sporostatia* Mass.

***S. polyspora* (Nyl.) Grumm.—On rock, NE.

*S. testudinea* (Ach.) Mass.—On rock, NE, SW; several varieties.

*Staurothele* Norm. *nom. cons.*

*S. cf. fissa*—On rock, SD; hymenial algae often elongated.

***S. fuscocuprea* (Nyl.) Zsch.—On rock, CD, NE, SD, SW, SDT; rather variable, often with poorly developed thallus.

*Stenocybe* Nyl. *ex* Körb.

**S. euspora* (Nyl.) Arn.—On wood, CD.

*Stereocaulon* Hoffm. *nom. cons.*

*S. alpinum* Laur.—On soil or moss, NE, SD, SW; quite variable, often poorly developed.

*S. cf. condensatum*—On soil, NE, SW, SD; probably a mixture of several taxa; often poorly developed.

*S. cf. glareosum*—On soil, NE, SD; distinguished mainly by large reddish cephalodia; phyllocladia not very elongated.

***S. grande* (Magn.) Magn.—On soil, SW.

*S. cf. rivulorum*—On soil and rock, NE; probably a mixture of several taxa.

*Thamnolia* Ach. *ex* Schaer. *nom. cons.*

*T. vermicularis* (Sw.) Ach. *ex* Schaer.—On soil, moss, or rock, NE, SW, SD; both v. *vermicularis* and v. *subuliformis* (Ehrh.) Schaer, usually mixed together.

*Trapeliopsis* Hertel & Schneider

*T. granulosa* (Ehrh.) H. T. Lumbisch in Hertel—On soil, moss, or rotten wood, CD, NE, SD, SDT; often sterile.

*Tremolechia* Choisy

**T. atrata* (Ach.) Hertel—On rock, NE, SW, SD.

*Umbillicaria* Hoffm.

*U. cylindrica* (L.) Del.—On rock, NE, SW; several varieties.

*U. deusta* (L.) Baumg.—On rock, NE, SD.

*U. hyperborea* (Ach.) Hoffm.—On rock, NE, SW, SD; several varieties; apothecia often with few gyri.

**U. kraschenikovii* (Sav.) Schol.—On rock, SW.

*U. proboscidea* (L.) Schrad.—On rock, NE, SW; two varieties.

*U. torrefacta* (Lightf.) Schrad.—On rock, NE, SW.

**U. virginis* Schaer.—On rock, SW.

*Verrucaria* Schrad. *nom. cons.*

***V. elaeomelaena* (Mass.) Arn.—On rock, NE.

**V. margacea* (Wahlenb.) Wahlenb.—On rock, NE.

*Vestergrenopsis* Gyeln.

***V. isidiata* (Degel.) Dahl—On rock, NE, SD.

*Xanthoria* (Fr.) Th. Fr. *nom. cons.*

*X. candelaria* (L.) Fr.—On rock, SW; poorly developed.

*X. elegans* (Link) Th. Fr.—On rock, NE, SW; several varieties.

***X. sorediata* (Vain.) Poelt—On rock or moss, NE, SW.

*Xylographa* (Fr.) Fr.
*X. abietina* (Pers.) Zahlbr.—On wood, SDT.
*X. hians* Tuck.—On wood, SD, SDT.

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# Growth and Population Structure of the Short-Horned Lizard (*Phrynosoma douglassi*) and the Sagebrush Lizard (*Sceloporus graciosus*) in southeastern Idaho

**Abstract**

A mark-recapture study of the short-horned lizard (*Phrynosoma douglassi*) and the sagebrush lizard (*Sceloporus graciosus*) was conducted during 1976 and 1977 on the Idaho National Engineering Laboratory site in southeastern Idaho. Three age classes were evident in both species: young-of-the-year, juveniles, and adults. In both species, adult females were significantly larger than adult males. This appears to be due to continued growth of first year adult females and cessation of growth in similarly sized males. Both species maintained densities of approximately 14 individuals per 1 ha grid. Survival of adults over winter was high in adults of both species. Survival of juvenile *S. graciosus* was similar to that of adults, whereas survival of young-of-the-year and juvenile *P. douglassi* was lower than that of adults. The larger juvenile mortality seen in *P. douglassi* may be related to greater reproductive effort of this species when compared to *S. graciosus*. Both species exhibit the long-lived iteroparous reproductive strategy. The fact that females were larger than males in both species may be related to this reproductive strategy.

## Introduction

Lizards are important components of North American desert ecosystems, rivaling mammalian and avian species in ecological importance with respect to numbers, biomass, and energetics (Turner *et al.* 1976). Population ecologists have found lizards to be excellent experimental organisms for testing theories of life history strategies (Tinkle 1969a) and of niche structure and function (Pianka 1973). Unfortunately, most studies of lizard ecology have been performed on populations inhabiting the southwest deserts of North America. Important corollaries to theories developed from these populations have been proposed for tropical and north temperate lizards but few studies in the latter two geographic regions have been performed. Studies are needed on species and genera which occur over wide geographic areas. Two such species in North American desert ecosystems are the short-horned lizard (*Phrynosoma douglassi*) and the sagebrush lizard (*Sceloporus graciosus*). *P. douglassi* is the most widely distributed member of the genus *Phrynosoma* and *S. graciosus* is among the most widely distributed members of the genus *Sceloporus* (Stebbins 1954).

The major objective of this study was to collect data on selected ecological aspects of *P. douglassi* and *S. graciosus* near the northern limits of their ranges.

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Estimates of growth rates, population size, survivorship, and sex ratios are compared with predictions made by theories of reproductive strategies.

### Study Area

The study was conducted during 1976 and 1977 on the Idaho National Engineering Laboratory (INEL) site located in Bingham, Bonneville, Butte, Clark, and Jefferson counties of southeastern Idaho. The area is located at an elevation of ca 1500 m. It is characterized by rolling hills produced by recent lava flows covered by alluvial and loessial deposits. Summers are hot (maximum and minimum temperatures averaging 30.5 and 10.0 C, respectively) and winters cold (maximum and minimum temperatures averaging -2.7 and -16.1 C, respectively). The average yearly precipitation is 21.6 cm mostly in the form of spring rains. Much of the data were collected on a 1 ha grid systems that was 100 m on each side and had grid stakes placed 10 m apart. This grid system and the surrounding area were dominated by big sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus nauseosus*), halogeton (*Halogeton glomeratus*), and squirreltail grass (*Sitanion hystrix*).

### Methods

Lizards on the grid were captured by hand or noose, sexed, and measured snout-to-vent (SVL) to the nearest mm. Individuals were marked permanently by toe clip and, for field identification, by painting legs various colors with felt-tipped markers. The location of each capture site was recorded by estimating the distance from this site to the nearest two grid stakes. These sites were later plotted on maps of the grid. Recaptures were made periodically throughout the two years, particularly when color marks were lost through shedding. These individuals were remeasured, reweighed, and released. Lizards retaining their color marks were relocated within the grid system and their positions recorded. The perimeter of the grid was periodically sampled for a distance of 50 m from each side in an effort to find migrant individuals. Additionally, many lizards from areas around the grid were captured and marked for other aspects of this study (Guyer 1978). Sex and SVL data from these lizards were used in determining age and sex groups as were similar data collected from lizards on the grid.

Growth rates were estimated from lizards measured two or more times and by linear regression of SVL on time of year. The latter method was used to test for differences in size patterns of males and females (analysis of covariance). Because both species appeared to lay a single clutch which hatched over a short period of time (2 weeks, Guyer 1978), the slope of each regression line should reflect average growth rates within each age and sex group. Data for each of the two years were treated separately. Capture-recapture data were used to estimate population size via Jolly's method (Jolly 1965).

### Results

Size data for *P. douglassi* were based on 83 captures of 69 individuals in 1976 and 161 captures of 130 individuals in 1977 (Figure 1). Three age groups for each sex were present during both years: young-of-the-year (YOY), juveniles (entering first full year), and adults (entering second full year or older). Juvenile males were

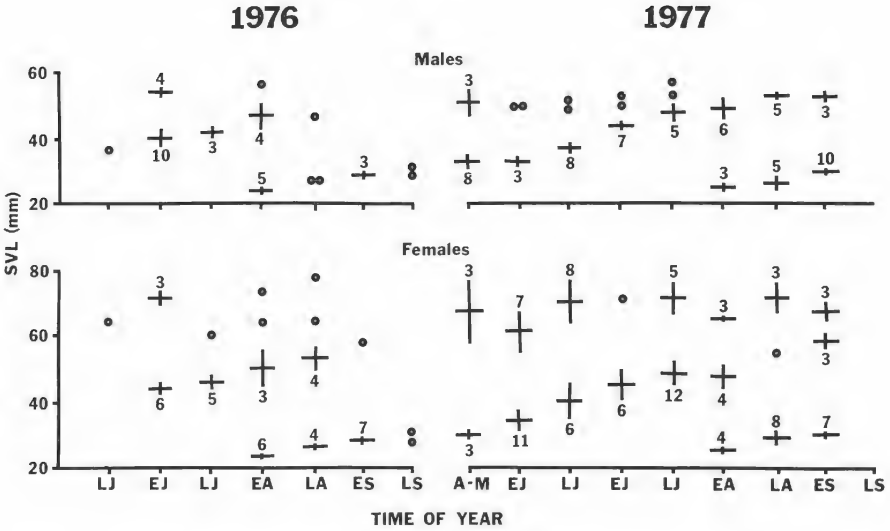


Figure 1. The relationship between snout-vent length of *Phrynosoma douglassi* and time of year. Horizontal bars are means, vertical bars are ± 1 sd, numbers are sample sizes, and dots are single observations. Time of year extends from April-May (A-M) to late September (LS).

smaller than adult males from April to August after which the two groups became indistinguishable. Little or no growth occurred in males after early August. Juvenile females were smaller than adult females throughout both years, although they approached adult size by early September. Growth in juvenile females occurred throughout the active season.

Adult females were significantly larger than adult males for *P. douglassi* during both years (Table 1). There was no significant difference between the slopes of SVL data for juvenile or YOY males and females (Table 2). Thus, there was no difference in growth rate of male and female YOY or juveniles. When adjusted for the effect of time, juvenile females were significantly larger than males during both years. Female YOY were larger than males during 1977 but not 1976 (Table 2).

TABLE 1. Sizes of adult *P. douglassi* and *S. graciosus*.

| *Species and Year* | *Sex* | *Mean* | *S.E.* | *N* | *T-value* |
|---|---|---|---|---|---|
| *P. douglassi* 1976 | M | 54.2 | 1.0 | 5 | 7.1* |
| | F | 69.8 | 1.6 | 9 | |
| *P. douglassi* 1976 | M | 52.0 | 0.7 | 10 | 8.0* |
| | F | 68.2 | 1.3 | 22 | |
| *S. graciosus* 1977 | M | 57.4 | 0.3 | 46 | 4.6* |
| | F | 59.8 | 0.4 | 54 | |

*significant at 0.05 level.

TABLE 2. Results of analysis of covariance for young-of-the-year (YOY) and juvenile lizard sizes on time of year. N refers to sample size and F refers to F-tests of equality of slopes and equality of adjusted mean snout-vent-length (SVL), respectively.

| Species, Age and Year | Sex | N | Slope | F | Adjusted $\bar{X}$ SVL ± se | F |
|---|---|---|---|---|---|---|
| *P. douglassi* | | | | | | |
| YOY 1976 | M | 12 | 0.11 | 2.03 | 27.2 ± 0.3 | 0.001 |
| | F | 17 | 0.15 | | 27.2 ± 0.2 | |
| YOY 1977 | M | 18 | 0.15 | 0.68 | 28.2 ± 0.3 | 11.88* |
| | F | 19 | 0.17 | | 29.6 ± 0.3 | |
| Juv. 1976 | M | 19 | 0.14 | 1.42 | 42.8 ± 0.7 | 31.55* |
| | F | 19 | 0.20 | | 48.3 ± 0.7 | |
| Juv. 1977 | M | 39 | 0.20 | 2.52 | 43.0 ± 0.6 | 9.29* |
| | F | 43 | 0.25 | | 45.4 ± 0.5 | |
| *S. graciosus* | | | | | | |
| YOY 1977 | M | 49 | 0.01 | 2.15 | 28.4 ± 0.3 | 6.44* |
| | F | 46 | 0.09 | | 29.7 ± 0.4 | |
| Juv. 1977 | M | 22 | 0.14 | 1.52 | 51.5 ± 0.3 | 0.54 |
| | F | 18 | 0.17 | | 51.1 ± 0.4 | |

*significant at 0.05 level

Table 3 presents the known growth rates of adult female *P. douglassi*. Growth rates of two females known to have been juveniles in 1976 were significantly greater than other adult females (one-tailed Mann-Whitney U-test, $p < 0.05$). Thus, females entering their first year of adulthood grew faster than older adult females. Insufficient data were collected to compare growth in adult males in a similar fashion. However, the size data (Figure 1) suggest that all adult males grow at the same slow rate.

TABLE 3. Growth rates of female lizards during 1976 and 1977. Stars (*) indicate animals known to have been juveniles in 1976.

| Species | Animal Number | △SVL (mm) | △Time (days) | Growth Rate (mm/day) |
|---|---|---|---|---|
| *P. douglassi* | 34* | 6.0 | 27 | 0.14 |
| | 49* | 14.0 | 83 | 0.17 |
| | 3 | 0.0 | 54 | 0.00 |
| | 21 | 3.0 | 48 | 0.06 |
| | 21 | 5.0 | 89 | 0.03 |
| | 76 | 3.0 | 113 | 0.03 |
| | 95 | 2.0 | 76 | 0.03 |
| | 140 | 1.0 | 35 | 0.03 |
| | 156 | 0.0 | 13 | 0.00 |
| *S. graciosus* | 6* | 4.0 | 42 | 0.09 |
| | 12* | 5.0 | 126 | 0.04 |
| | 67* | 3.0 | 30 | 0.11 |
| | 8 | 1.0 | 88 | 0.01 |
| | 32 | 0.0 | 20 | 0.00 |
| | 37 | 2.0 | 59 | 0.03 |
| | 84 | 2.0 | 23 | 0.08 |
| | 114 | 0.0 | 15 | 0.00 |

*S. graciosus* size data are based on 276 captures of 256 individuals in 1977 (Figure 2). Three age groups were evident: YOY, juveniles, and adults. Juveniles smaller than 40 mm were too light to be noosed and were difficult to hand capture. Also, this group was not commonly seen until late in the year. Consequently, few juveniles were captured early in the year. Juvenile males formed a distinct

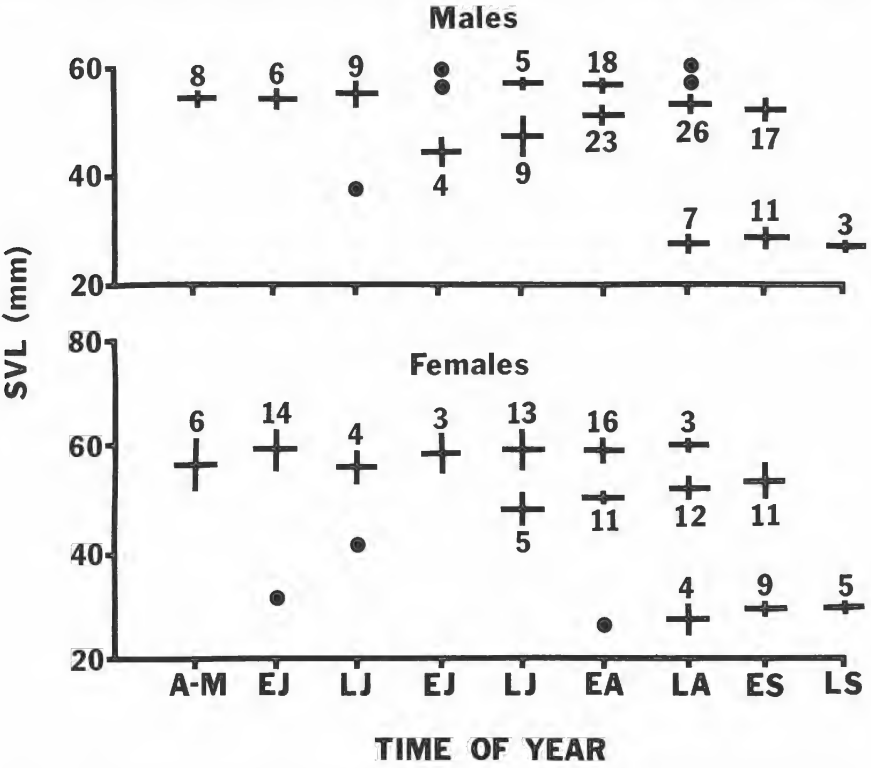


Figure 2. The relationship between snout-vent length of *Sceloporus graciosus* and time of year. See Figure 1 for explanation of graph.

group, based on SVL, until early August when they entered adult size. Little or no growth occurred in this group after early August (Figure 2). Juvenile females were distinguishable from adults throughout the active season (Figure 2).

As in *P. douglassi,* adult female *S. graciosus* were significantly larger than males (Table 1). There was no significant difference in the slopes of SVL data for juvenile males versus females nor was there a difference in adjusted mean size. However, YOY females were significantly larger than males even though these lizards did not appear to grow during the short time period over which they were captured in 1977 (Table 2).

From known growth rates of adult female *S. graciosus* (Table 3), females known to have been juveniles in 1976 grew faster than other females (one-tailed Mann-Whitney U-test, $p < 0.05$). Again, insufficient data were available to analyze growth rates in males. However, since juvenile males reach adult size by the end of their

juvenile year (Figure 3) it seems unlikely that first year adult males grow at a faster rate than older males.

Jolly's estimate of population size ($\bar{X} \pm 1$ S E) for *P. douglassi* averaged 14.3 ± 2.1 during 1976 and 14.6 ± 2.1 during 1977. Survival of *P. douglassi* over winter (percentage of animals marked in 1976 that were recaptured in 1977) was low in YOY and juveniles and high in adults (Table 4). Of 124 *P. douglassi* captured and marked outside the grid, three were emigrants from the grid. All were juveniles. One established a home range approximately 60 m north of the grid and two were recaptured approximately 500 m south of the grid. Two other lizards, both juveniles first captured outside the grid, were later recaptured within the grid's boundary. One of these established a home range.

Sex ratios for *P. douglassi* did not differ significantly from a one-to-one ratio for YOY or juveniles (27 males: 35 females for YOY and 46:46 for juveniles; chi-square goodness of fit, $p < 0.05$ in both cases). The sex ratio for adults was significantly different from a one-to-one ratio (14:29; $p > 0.05$). Since there was no significant difference (chi-square test of homogeneity, $p > 0.05$) between years for any age and sex group, data for both years were pooled.

Population size estimates for *S. graciosus* averaged 14.0 ± 5.1 for 1976 and 12.0 ± 2.2 for 1977. Over-winter survival of juveniles was slightly greater than that of adults (Table 4). Too few YOY were captured to estimate their over-winter survival. Sex ratios of *S. graciosus* did not differ significantly from a one-to-one ratio for YOY or adults (22:16 for YOY and 49:58 for adults; chi-square goodness of fit, $p < 0.05$ in both cases). Significantly more juvenile males were captured than juvenile females (67:42; $p < 0.05$). Of 249 *S. graciosus* marked outside the grid, none emigrated off the grid and none immigrated onto it.

TABLE 4. Survivorship over winter (1976-1977) for *P. douglassi* and *S. graciosus* in southeastern Idaho.

| Species | Age | # Captured in 1976 | # Captured in 1977 | Survival |
|---|---|---|---|---|
| *P. douglassi* | YOY | 19 | 2 | 0.11 |
| | Juv. | 13 | 2 | 0.15 |
| | Adult | 6 | 4 | 0.67 |
| *S. graciosus* | YOY | 0 | --- | --- |
| | Juv. | 5 | 4 | 0.80 |
| | Adult | 14 | 9 | 0.64 |

**Discussion**

A common feature of the two species was a sexual dimorphism in size. Pianka and Parker (1975) noted a similar dimorphism in *P. douglassi* from Utah. Sexual dimorphism of size has been reported for *S. graciosus* in northern California (Stebbins 1944), Wyoming (Kerfoot 1968), and Utah (Burkholder and Tanner 1974). This size difference could result from a differential in size at birth, growth rates of YOY or juveniles, or length of growth period. *P. douglassi* YOY females were larger than YOY males during 1977 but not 1976. Thus, my results on differential size at birth in this species are equivocal. However, the small size difference between YOY males and females in 1977 is not enough to explain the large difference

in adults. For *S. graciosus*, YOY females were significantly larger than males, but no such difference was found in juveniles (born the previous year). Again, results for differential size at birth are equivocal. Growth rates between sexes for YOY or juveniles were not statistically different in either species. In contrast, Pianka and Parker (1975) reported that juvenile females grow faster than juvenile males. In this study, continued growth in females entering their first year of adulthood occurred in both species while similarly aged males appeared to cease growth. Similar results were reported for *S. graciosus* by Stebbins (1944) and Burkholder and Tanner (1974). Continued growth of young adult females is the most likely mechanism causing sexual dimorphism of size in the two species.

Another common growth feature of the two species was the number of age classes. Similar classes were found by Pianka and Parker (1975) for *P. douglassi* and by Stebbins (1944), Mueller and Moore (1969), and Goldberg (1975) for *S. graciosus*. Tinkle (1973) and Burkholder and Tanner (1974) were able to distinguish four age groups for *S. graciosus*.

Horned lizards typically maintain low population densities when compared to other iguanids (Pianka and Parker 1975). Densities of 1.6/ha for *P. cornutum* in New Mexico (Worthington 1972), 1.0/ha and 5.0/ha for *P. platyrhinos* in Nevada (Medica *et al.* 1973, Tanner and Krogh 1973) have been reported. However, in this study densities of 14.3/ha and 14.6/ha occurred in 1976 and 1977, respectively. The high observed density of *P. douglassi* may have been due to selection of the study site based on the relatively large numbers of horned lizards seen there by previous investigators (Sehman and Linder 1978). Densities of *S. graciosus* during the two years were lower than the 206 to 216/ha reported by Tinkle (1973) or the 63 to 73/ha by Burkholder and Tanner (1974).

Survival patterns for both species indicated that they are long-lived as adults. This conclusion was also reached by Medica, *et al.* (1973), Tanner and Krogh (1973), and Pianka and Parker (1975) for *P. douglassi* and by Stebbins (1948) and Tinkle (1973) for *S. graciosus*. Juvenile over-winter survival differed between the two species. Low survival of juvenile *P. douglassi* occurred during this study. Similar results were reported by Medica *et al.* (1973) and Pianka and Parker (1975). High survivorship, even exceeding that of adults, was found in juvenile *S. graciosus*. Burkholder and Tanner (1974) showed similar survival for juvenile *S. graciosus* and Tinkle (1973) found juvenile survival to be greater than adult survival. The difference in juvenile survival between the two species may be important in explaining differences in reproductive output between them. The large clutch size of *P. douglassi* (Goldberg 1971) as compared to *S. graciosus* (Goldberg 1975) may be required to overcome the comparatively low juvenile survival.

Sex ratios of YOY did not differ from one-to-one for either species. Assuming equal numbers of males and females are born each year, any deviations from a one-to-one ratio in older age groups should result from survival or behavioral differences between sexes or to random chance. In *P. douglassi*, sex ratios deviated from one-to-one in the adult age group only. During both years more adult females were seen than males. This may indicate that juvenile males incur greater mortality while over-wintering or that mortality is greater in adult males than females. Territorial displays by adult male iguanids are thought to increase their risk of being preyed upon as compared to females (Tinkle 1973). This is unlikely in

*Phrynosoma* since these displays are greatly reduced and may serve no social function (Lynn 1965). Adult *S. graciosus* had a one-to-one sex ratio while for juveniles more males were captured than females. I suspect that this is a behavioral artifact since most juvenile males occupied highly visible locations, particularly in rocky areas. Thus, they may have been located and captured more frequently than females.

Several predictions have been developed relating latitudinal changes with shifts in life history strategies. Tinkle (1969a,b) denoted two life history strategies among lizard populations. One strategy involves high reproductive effort (large clutch size or high clutch frequency), semelparity, short adult life span, and territoriality whereas the other strategy involves low reproductive effort, iteroparity, long adult life span, and dominance hierarchies. Hirshfield and Tinkle (1975) speculated that environmental predictability may determine which strategy evolves in a given population. In highly unpredictable environments, where survival of young may be negligible during certain years, individuals that devote relatively little effort to any one reproductive season and have long life spans would be at a selective advantage over individuals which devote most or all of their reproductive effort to one season. The reverse would be true in areas where environments favorable to juveniles are predictable. Pianka (1967) has shown that the northern Great Basin desert has the most unpredictable environment of any North American desert. Therefore, lizards present there should belong to the long-lived, iteroparous group. Both species in this study conformed to these predictions. Adults of both species commonly survived through two or more reproductive seasons and should thus be termed long-lived. They clearly did not exhibit the high mortality of adults characteristic of short-lived species. The small variation in SVL data at each sample date for YOY *P. douglassi* during each year suggests synchronous production of a single clutch in this species. The gestation period of *P. douglassi* probably restricts this species to a single clutch throughout its geographic range. Much more variation in SVL occurred in *S. graciosus* YOY which could indicate greater variation in development time for this egg-laying species or that two clutches are laid. The former mechanism is probably more likely since a single clutch is typical for northern populations of *S. graciosus* (Fitch 1970, Burkholder and Tanner 1974). Thus, both species would appear to be iteroparous.

Fitch (1978) suggested that a shift in sexual dimorphism of size should occur in these two reproductive strategies. In populations that are highly territorial, males should be larger. In populations selected for long life and iterated breeding, females should be larger. Both species in this study fit the latter prediction. A shift occurs in sexual dimorphism of size in *S. graciosus* for southern populations as males are larger than females in southern Utah (Tinkle 1973). This shift fits the geographic change in reproductive strategy predicted by Tinkle (1969a,b). An apparent contradiction to this pattern of size dimorphism and reproductive strategy was reported by Mueller and Moore (1969) who found no difference in the total length of adult males and females for *S. graciosus* from Wyoming. Since tails are generally longer in males than in females (Kerfoot 1968), sexual dimorphism of size may have been masked. A key factor in testing predictions made by theories of reproductive strategies and sexual dimorphism of size is social organization. This aspect of the ecology of the two lizards was not determined. This appears to be a fruitful line

of research especially for *S. graciosus* since the current information would predict a change from territorial behavior in southern populations to dominance hierachies in northern populations.

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# Avian Interactions with Mid-Columbia River Water Level Fluctuations

**Abstract**

Fluctuating water levels from 40 years of dam operations along the mid-Columbia River create environmental subsidies for birds. Members of the ground feeder guild and the water gleaner guild receive a food subsidy from daily water level fluctuations which strand aquatic organisms on shore and terrestrial organisms are also swept into the water. Riparian plants, especially willows (*Salix* ssp.), are also slowly invading gently sloping shorelines as daily water level fluctuations frequently moisten historically summer-dry soils providing new nesting and perching sites for passerine birds.

There are also some negative influences. Daily fluctuating water levels and erratic spring surges in the Yakima Delta area are apparently inhibiting shoreline ground nesting birds, especially waterfowl.

## Introduction

The water level of the mid-Columbia River fluctuates in response to seasonal variations in runoff and the operation of a series of dams for hydropower production.

Reservoirs distributed along the Columbia River are manipulated to store water while supplying needs for electricity. This manipulation moderates the extreme annual variations in water level caused by natural runoff, and causes the water level to vary throughout the day as electricity is generated in response to daily demands for electrical power.

As electricity is generated, water is discharged through the dam turbines in varying amounts according to demand. These discharges travel downriver in response to a number of variables. Discharge intensity, distance from dam, cross-sectional channel area, acceleration due to gravity, frictional slope and wind are some of the important variables (Sneider and Skagg 1983). Although complex, their study did not consider interactions between a discharge wave and the downstream tailwater fluctuations. Therefore it is difficult to predict the magnitude of a water level change. Sometimes the water level gently rises and falls as little as 0.1 meter, while at other times surges as great as 2.6 meters pass downriver. The purpose of this study was to identify interactions between fluctuating water levels and the riverine avian community over the course of a year, June 1982-June 1983.

## Study Area

The study area is the lower portion of the Hanford Reach of the undammed section of the Columbia River between Priest Rapids dam and the tailwaters of Lake Wallula, the reservoir created by McNary dam (Figure 1).

Although the Hanford Reach is a flowing river, water levels fluctuate daily due to changing discharges from Priest Rapids Dam. Shoreline beaches are mostly gently sloping, and their substrates are a mixture of rocks, gravel and sand. A thin corridor of riparian vegetation occurs between the river and the semi-arid upland

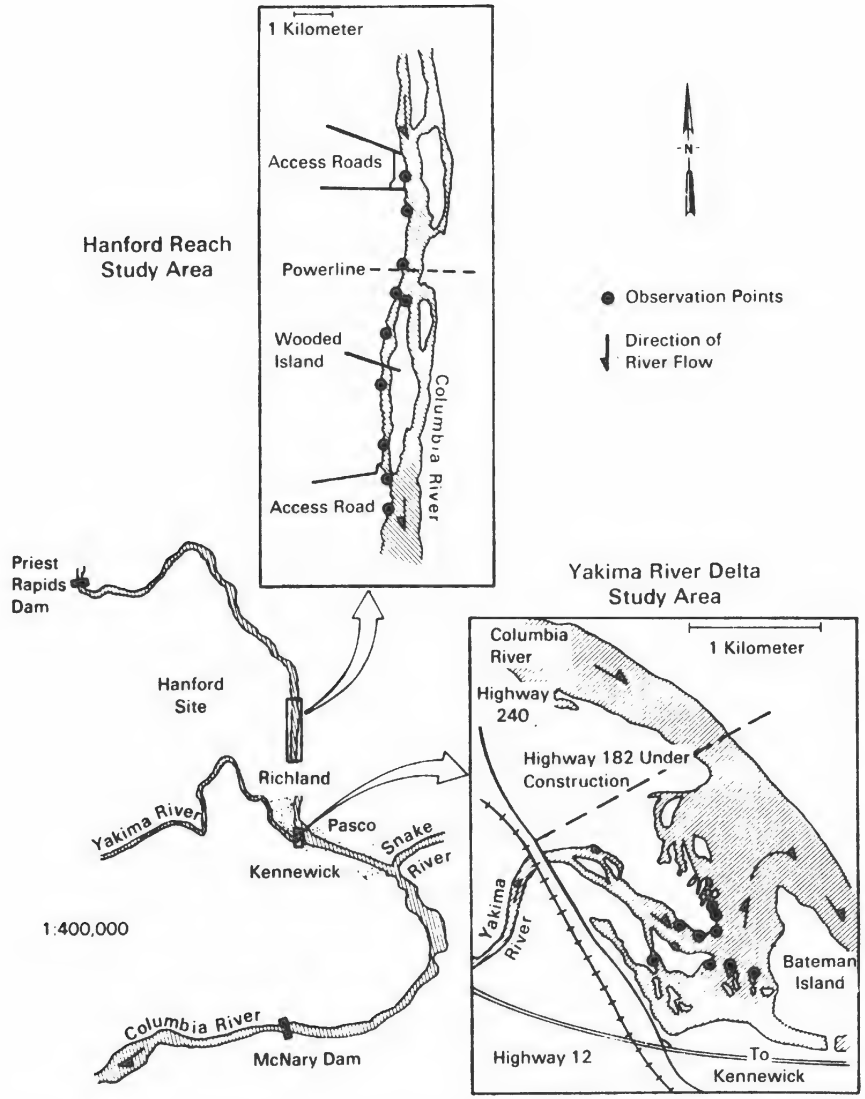


Figure 1. Map showing the locations of the two study areas along the Columbia River near Richland, Washington and the locations of the avian observation points in the Hanford Reach and the Yakima Delta study areas.

*Purshia tridentata-Artemisia tridentata/Bromus tectorum* community (Rickard and Rogers 1983). Riparian vegetation includes shrub-willow (*Salix* spp.), mixed grasses and forbs, and scattered, depauperate groves of cottonwood (*Populus trichocarpa*). Human intrusion on the western shoreline of the Hanford Reach is minimal due to security regulations imposed by the U.S. Department of Energy.

The water level fluctuates at the Yakima River delta due to upriver Priest Rapids Dam, downriver discharges and storage operations at McNary Dam, and flow changes in the Yakima River. Shorelines are nearly flat, consisting of mudflats at low water periods, and dense thickets of shrub willows, tree willows, peach-leaf willow (*Salix amygdaloides*), rank grasses (mostly reed canary grass, *Phalaris arundinacea*), cattail (*Typha latifolia*), bulrush (*Scirpus* spp.), Box elder (*Acer negundo*), Silver maple (*Acer saccharinum*), Russian olive (*Eleagnus angustifolia*), and a few cottonwoods. The birds of the Yakima River Delta are affected by a variety of human activities including year-round water recreation (fishing, hunting, boating) and sewage discharges from Richland and upstream towns on the Yakima River.

#### Methods

In order to identify avian interactions with erratic water level fluctuations, the activities and riverine habitat uses by birds were recorded. A total of 880 hours of observations were logged between June 1982 and June 1983 at ten locations along the Hanford Reach of the Columbia River and ten locations in the Yakima River Delta (Figure 1). Observations were made during two hour periods at sunrise and sunset, twenty days each month. Observation points were accessed by canoe.

The large number of observations (108,333 birds in 28,092 observations) were filed and retrieved by computer using Datatrieve (Digital Equipment Corporation 1980). In this program, multi-key, index sequential files were organized into detailed records of avian habitat use and activity sorted by species or by guild. These records were then compared with water level changes measured at reference points established in each study area. Bird taxonomy follows the A.O.U. Checklist (1983).

#### Results and Discussion

##### Feeding Behavior Interactions with Fluctuating Water Levels

Observations of feeding behavior of birds were cataloged into guilds. A guild is a group of species that exploit the same class of environmental resources in a similar way (Root 1967). In this study, seven feeding guilds were identified: (1) ground feeders, (2) water surface gleaners, (3) vegetation gleaners, (4) aerial insect feeders, (5) herbivores, (6) fishers and (7) raptors. Although all food energy routes may be affected by fluctuating water levels, ground feeding and water surface gleaning were observed to be the most directly affected.

Feeding behavior and water level fluctuation observations indicate that as the water levels recede from the beaches or mudflats, aquatic organisms are stranded. Kroger (1973) studied the effects of fluctuating water levels on aquatic organisms in the upper Snake River in Wyoming, and found that mayflies, stoneflies, caddis flies, dipterans, beetles, water mites, small fish, clams, and snails were stranded by receding water levels. Becker, Fickeisen, and Montgomery (1981) studied the impact of fluctuating water levels on fish in the Hanford Reach, and observed that

juvenile Chinook salmon, smallmouth bass, crappie, carp, bullhead, catfish, suckers, and sculpin were stranded by receding water levels.

Ground feeding along shorelines was observed to be more frequent when water levels were receding. The high mobility, visual prowess and the vocalizations uttered by birds seemed to facilitate opportunistic foraging on the exposed shorelines. The proportion of feeding observed during periods of receding water level (Table 1) is significantly higher than would be expected by chance alone. Also, some shorelines seemed to trap more aquatic organisms than others: mudflats, gravel, sand and grassy shorelines more than rocky shorelines. Perhaps these kinds of shorelines provide more entrapment sites than do the coarser rocky shorelines.

TABLE 1. Analysis of the ground feeding guild and fluctuating water levels.

| Type of Ground Feeding | Number of Observations | Proportion of Observations During Receding Water Levels | Chi-Square Values |
|---|---|---|---|
| Rock Pickers | 166 | .78 | 55.5[a] |
| Gravel Pickers | 250 | .87 | 135.4[a] |
| Sand Pickers | 110 | .89 | 67.2[a] |
| Mud (Silt Deposits) (Probers and Pickers) | 878 | .59 | 29.2[a] |
| Grass Pickers | 988 | .82 | 396.6[a] |
| Wading Bottom-Probers | 35 | .27 | 8.3[b] |

Ho: P = 1/2 testing whether observations of ground feeding occur randomly with respect to receding water levels

[a]Ho: P = 1/2 rejected, $p < .001$, critical value = 10.8, df = 1

[b]Ho: P = 1/2 rejected, $p < .01$, critical value = 6.6, df = 1

Some birds used a variety of substrates and others only a few (Table 2). In summer, species most commonly observed ground feeding along newly exposed shorelines were the Canada Goose, Killdeer, Spotted Sandpiper, and Red-winged Blackbird (Books 1984). Fall migration brings hundreds of Water Pipits to the river, where they were observed to feed on the rocky shorelines along the Hanford Reach. Migrating shorebirds were also common shoreline ground feeders in the fall. In winter, waterfowl epecially Canada Geese, Mallards, and American Coots were feeding on the shorelines. During the spring breeding season, Marsh Wrens, Bewick's Wrens, and Song Sparrows were common along the muddy shorelines of the Yakima River Delta, while Black-billed Magpies and Red-winged Blackbirds were more common along the Hanford Reach. Birds (including California Quail, Ring-necked Pheasants, Western Meadowlarks, and Long-billed Curlews) from surrounding communities also were observed feeding along newly exposed shorelines.

Members of the water surface gleaner guild may also receive a food subsidy from fluctuating water levels. Terrestrial insects, plant debris, and organic detritus from shorelines are carried along as water levels rise and flow rates accelerate. Water surface gleaners may feed on these allochthonous foods in addition to aquatic foods. Due to the distance between the point where terrestrial foods are introduced

into the river and the point where food items are ingested, it was not possible to quantify this effect in terms of avian use as was the case with shoreline ground feeding birds (Table 1). Commonly observed water surface gleaners are Mallards, Green-winged Teal, Ring-billed Gulls and California Gulls (Books 1984).

TABLE 2. Summary of the feeding substrates used by shoreline feeding birds along the Hanford Reach and the Yakima River Delta areas of the Columbia River near Richland, Washington, June 1982-June 1983.

| [1]Number of Feeding Substrates Used | Avian Species |
|---|---|
| | ----------Hanford Reach---------- |
| 5 | Killdeer (a,b,d,e,f), Spotted Sandpiper (a,b,d,e,f), Black-billed Magpie (a,b,d,e,f) |
| 4 | Horned Lark (a,b,e,f), Red-winged Blackbird (a,b,e,f) |
| 3 | Western Sandpiper (b,e,f), Greater Yellowlegs (b,e,f), Northern Flicker (a,b,f), Western Meadowlark (a,b,e) |
| 2 | Canada Goose (a,d), Ring-necked Pheasant (a,f), Long-billed Curlew (a,e), California Gull (a,e), Mourning Dove (a,e), Water Pipit (b,f), White-crowned Sparrow (a,b) |
| 1 | Mallard (d), Green-winged Teal (b), California Quail (a), Mountain Plover (e), Common Snipe (e), Ring-billed Gull (e), American Crow (e), Marsh Wren (a), American Robin (b), European Starling (a), House Sparrow (a), Yellow-headed Blackbird (a), Brewer's Blackbird (a), Brown-headed Cowbird (a), Rufous-sided Towhee (a), House Finch (a), Savannah Sparrow (a), Vesper Sparrow (f), Lark Sparrow (a), Lincoln Sparrow (f), Grasshopper Sparrow (a) |
| | ----------Yakima River Delta---------- |
| 4 | Black-billed Magpie (a,b,c,e) |
| 3 | Greater Yellowlegs (c,e,g), Long-billed Dowitcher (c,e,g) |
| 2 | Canada Goose (a,e), Greater Yellowlegs (a,d), Long-billed Dowitcher (a,d), Western Sandpiper (c,d), California Gull (c,e), Ring-billed Gull (c,d), Marsh Wren (a,d), Red-winged Blackbird (a,c), Song Sparrow (a,c) |
| 1 | Black-crowned Night Heron (d), Mallard (e), American Wigeon (d), American Coot (c), Killdeer (c), Common Snipe (d), Pectoral Sandpiper (c), American Avocet (d), Northern Flicker (a), American Crow (e), Bewick's Wren (a), American Robin (a), Water Pipit (c), European Starling (b), Brown-headed Cowbird (a), American Goldfinch (a) |

[1]Substrate feeding types: Grass (a), Sand (b), Mudflat (pick) (c), Mudflat (probe) (d), Gravel (e)

#### Nesting Interactions with Fluctuating Water Levels

Birds are most vulnerable to water fluctuation while nesting. During the period of egg incubation, and chick care for altricial species, birds are susceptible to adverse impacts of fluctuating water levels. Wolf (1955) documented waterfowl losses on three lakes in Utah, and found that there was significant loss of duck nests due to rising water. Other shoreline ground nesters, such as American Coots and Western Grebes, abandoned their nests as they became exposed by receding water levels.

In this study, reproductive success was monitored by noting general locations of nests, habitat associations of nest sites and sightings of young. Ground-nesting birds which place their nests above the zone of the most extreme fluctuating water levels nested successfully, e.g., Canada Geese, Mallards, gulls, terns, shorebirds.

The semi-marsh conditions, 1 to 1 ratio of open water to emergent vegetation, of the Yakima River Delta were expected to provide a habitat favorable for waterfowl reproduction (Bishop *et al.* 1979, Weller and Spatcher 1965, Weller and Fredrickson 1974). However, observed waterfowl reproduction in the delta was very low. Pairs of Northern Pintail, Mallard, Canada Goose, Blue-winged Teal, Cinnamon Teal, Northern Shoveler, Canvasback, Lesser Scaup, Bufflehead, Redhead and Common Merganser were observed in the delta throughout the breeding season but the only young birds seen were five Canada Geese. At the same time, Common Loons, Mallards and Common Mergansers successfully raised young along the Hanford Reach along with many broods of Canada Geese indicating that fluctuating water levels did not hinder reproductive success as much there.

Nests of Forster's terns and gulls are often located near the shore on their island colonies. These are destroyed when exceptional surges are sent downriver during the nesting period. Large surges of water in early June of 1982 appeared to cause mortality in the tern colony on an island located between the two study areas. However, a dramatic surge of over 2.5 meters in late June of 1984 caused little or no immediate mortality because the young terns were able to move inland away from the rising water level. Therefore the timing of exceptional surges is important in ground nesting reproductive success.

#### Avian Habitat Interactions with Fluctuating Water Levels

Willow thickets are expanding their acreages along the Columbia River shoreline. As Dewaard (1981) noted, the high flows that now characterize the Hanford Reach have caused changes in the species composition and the physiognomy of shoreline plant communities. Dam operations have altered the historic seasonal water flow patterns so that the spring freshet at maximal flow no longer severely scours the shorelines for a few weeks then recedes leaving the shoreline dry and sun-baked in summer. The daily fluctuating water levels seems to favor riparian growth by frequently bathing the gently sloping shores. As willows become established, they tend to slow the current and trap sediment and organic debris thus building sandbars and mudflats. Sandbars and mud provide new rooting substrates for willows and other riparian vegetation, which in turn provides additional bird habitat. Throughout the year, willows provide habitat for a wide variety of birds. Most species use the willows for perches, especially the passerines (Books 1984). Waterfowl use the dense thickets for cover in fall and winter. Ground feeding bird forage under the willows during spring and fall migrations. Willow thickets provide nesting sites suitable for birds that would otherwise not find suitable nesting sites in the surrounding acreages of treeless shrubsteppe plant communities. Some of these are the Black-crowned Night Heron, Yellow Warbler, Black-headed Grosbeak, Bewick's Wren, Northern Oriole, Eastern Kingbird, flycatchers and Black-billed Magpie. The expansion of willow thickets would appear to be favorable to nesting populations of these birds.

#### Conclusions

Fluctuating water levels from dam operations cause two forms of subsidy for birds. Members of the ground feeder guild and water gleaner guild receive a food subsidy

from daily fluctuations which strand aquatic organisms on the shorelines and which wash terrestrial foods into the water. Willows and herbaceous riparian vegetation are invading gently sloping shorelines as daily fluctuations moisten formerly dry soils and as dam operations inhibit drastic spring flooding.

Daily fluctuating water levels and erratic spring surges are apparently inhibiting shoreline ground nesting, especially of some species of waterfowl in the Yakima Delta.

**Taxonomic List of Birds Mentioned in the Text**

Common Loon
*Gavia immer*
Western Grebe
*Aechmophorus occidentalis*
Black-crowned Night Heron
*Nycticorax nycticorax*
Canada Goose
*Branta canadensis*
Mallard
*Anas platyrhynchos*
Northern Pintail
*Anas acuta*
Green-winged Teal
*Anas crecca*
Blue-winged Teal
*Anas discors*
Cinnamon Teal
*Anas cyanoptera*
American Wigeon
*Anas americana*
Northern Shoveler
*Anas clypeata*
Redhead
*Aythya americana*
Canvasback
*Aythya valisineria*
Lesser Scaup
*Aythya affinis*
Common Merganser
*Mergus merganser*
Forster's Tern
*Sterna forsteri*
Mourning Dove
*Zenaida macroura*
California Quail
*Callipepla californicas*
Ring-necked Pheasant
*Phasianus colchicus*
American Coot
*Fulica americana*
Killdeer
*Charadrius vociferus*
Common Snipe
*Gallinago gallinago*
Long-billed Curlew
*Numenius americanus*
Spotted Sandpiper
*Actitis macularia*
Greater Yellowlegs
*Tringa melanoleucus*
Pectoral Sandpiper
*Calidris melanotos*
Long-billed Dowitcher
*Limnodromus scolopaceus*
Western Sandpiper
*Calidris mauri*
American Avocet
*Recurvirostra americana*
California Gull
*Larus californicus*
Ring-billed Gull
*Larus delawarensis*
American Robin
*Turdus migratorius*
Water Pipit
*Anthus spinoletta*
European Starling
*Sturnus vulgaris*
Northern Flicker
*Colaptes auratus*
Eastern Kingbird
*Tyrannus tyrannus*
Horned Lark
*Eremophila alpestris*
Black-billed Magpie
*Pica pica*

American Crow
*Corvus brachyrhynchos*
Bewick's Wren
*Thryomanes bewickii*
Marsh Wren
*Cistothorus palustris*
Savannah Sparrow
*Passerculus sandwichensis*
Grasshopper Sparrow
*Ammodramus savannarum*
Vesper Sparrow
*Pooecetes gramineus*
Lark Sparrow
*Chondestes grammacus*
White-crowned Sparrow
*Zonotrichia leucophrys*
Lincoln's Sparrow
*Melospiza lincolnii*
Song Sparrow
*Melospiza melodia*
Yellow Warbler
*Dendroica petechia*
Western Meadowlark
*Sturnella neglecta*
Yellow-headed Blackbird
*Xanthocephalus xanthocephalus*
Red-winged Blackbird
*Agelaius phoeniceus*
Northern Oriole
*Icterus galbula*
Brown-headed Cowbird
*Molothrus ater*
Black-headed Grosbeak
*Pheucticus melanocephalus*
House Finch
*Carpodacus mexicanus*
American Goldfinch
*Carduelis tristis*
Rufous-sided Towhee
*Pipilo erythrophthalmus*

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# Comparison of Experimental Fall Burning and Clipping on Bluebunch Wheatgrass

## Abstract

This study compared the effects of autumn burning and clipping on bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribner and Smith) productivity the following spring. Dormant plants on a site in south-central Washington were treated either individually or as part of a 3.14 $m^2$ area centered on the study plant.

Clipping and burning shortened leaf lengths during the first growing season post-treatment. Shoot biomass and seedhead formation were both reduced by clipping but not by burning. The failure to detect measurable differences between plants treated individually and those treated as a part of a larger area suggests that bluebunch wheatgrass is not greatly influenced by burning or by clipping its neighboring plants. Differences in the effects of autumn burning and clipping on bluebunch wheatgrass productivity is likely the consequence of microclimatic differences.

## Introduction

Bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribner and Smith) is an important livestock forage grass in the semi-arid regions of the Pacific Northwest (Daubenmire 1970). Applied rangeland research has focused on the effects of burning and livestock grazing mainly for the purpose of maintaining or improving sagebrush-bunchgrass communities as a source of sustainable livestock forage. Most studies indicate that grazing and clipping inhibit shoot production in bluebunch wheatgrass to a degree dependent upon the intensity of the treatment (Wilson *et al.* 1966), the season of the year (Blaisdell and Pechanec 1949), and the amount of competition by its neighboring plants (Mueggler 1972). The response of bluebunch wheatgrass to burning, however, appears to be more variable. Increases in shoot productivity (Uresk *et al.* 1976, Daubenmire 1968) as well as temporary decreases have been reported (Mueggler and Blaisdell 1958, Willms *et al.* 1980).

The objective of this study was to compare the effects of autumn clipping and burning on bluebunch wheatgrass productivity the following spring. The study was also designed to test whether or not burning or clipping the surrounding neighboring plants influences the response of individual plants to the same treatment.

## Study Area and Methods

The study site is located on the Arid Lands Ecology (ALE) Reserve on the U.S. Department of Energy's Hanford Site in south-central Washington at an elevation of 366 m (1200 ft), on a gentle slope of less than 3 percent with an east facing

aspect. The soil is classified as Ritzville silt loam, and precipitation averages 25 cm (10 in.) annually (Thorp and Hinds 1977). The vegetation of the area is representative of stands of the *Artemisia tridentata/Agropyron spicatum* association (Daubenmire 1970). A wildfire in August 1973 killed most of the sagebrush (*Artemisia tridentata* Nutt.) in the study area, but the grasses quickly recovered from burning (Uresk *et al.* 1976). Bluebunch wheatgrass dominates shoot biomass with lesser amounts of Sandberg bluegrass (*Poa sandbergii* Vasey) and Thurber's needlegrass (*Stipa thurberiana* Piper) (Rickard *et al.* 1976).

A one-hectare study plot was established and a pilot study was conducted to determine the diameter size distribution of bluebunch wheatgrass. Two line transects were randomly located within the study plot, and the diameters of the first twenty-five bluebunch wheatgrass plants encountered on each line were measured. Sixty-two percent of the measured plants had diameters ranging between 10 and 18 cm. To minimize the influence of variable bunch diameter on experimental measurements, only those plants that were within the 10-18 cm size range were selected for study.

A randomized block design was used to minimize the effect of spatial heterogeneity. This required replication of treatments within equal subsections of the study plot. Thus, the plot was divided into four equal quadrants. In each quadrant 25 bluebunch wheatgrass plants were selected randomly. A plant was rejected for study if it was located within 4 m of a plant already chosen. In each quadrant, five study plants were assigned randomly to one of the following five treatments: 1. Plant clipped to crown level; surrounding vegetation undisturbed (clip plant); 2. Plant clipped to the crown level; surrounding vegetation within a 1 m radius clipped to the ground (clip area); 3. Plant burned; surrounding vegetation undisturbed (burn plant); 4. Plant burned; surrounding vegetation within a 1 m radius burned (burn area); 5. Plant not clipped or burned; surrounding vegetation undisturbed (control).

For the burn area treatments, sheet metal fences were used to confine the fire to either a single study plant or to a 3.14 $m^2$ area. Burning was initiated with a propane fueled flame. For the two clipping treatments, plants were clipped as close to ground level as practical, either individually or along with all the surrounding vegetation within a 1 m radius. The 3.14 $m^2$ size of the surrounding area treatment was chosen because the roots of bluebunch wheatgrass plants can extend approximately 70 cm laterally (Harris 1967) and because this size is similar to that used in other clipping studies (Mueggler 1972). All treatments were performed during the first week of September 1979.

Productivity was defined as live shoot biomass and was measured at the end of the spring growing season in July 1980. All study plants were collected by clipping, oven dried for 72 hr at 55°C, and weighed. For the control plants, live foliage was separated from standing dead foliage before weighing. A number of additional parameters were also measured as indicators of plant performance: leaf length (Uresk *et al.* 1976), flowering culm and seedhead lengths (Mueggler 1975), and seedhead number (Mueggler 1975, Blaisdell and Pechanec 1949). For each plant, 10 leaves and a maximum of 10 culms and seed heads were selected randomly for measurement.

Data obtained for each of the five measurements of plant performance were analyzed in three steps. First, an analysis of variance for a two-way classification

with replicated observations (Rao 1952) was used to test the general hypothesis that the treatments had an effect on the measurements. After determining the significance of variance among treatments for a particular measurement, treatment effects were examined using planned comparisons by means of orthogonal contrasts (Snedecor and Cochran 1975). Finally, a two-tailed Fisher's protected least significant difference (LSD) test was used to compare treatment means (Snedecor and Cochran 1975). Statistical significance was inferred at the $\alpha = 0.05$ level.

#### Results and Discussion

In general, all five measurements of plant performance showed similar responses to the various treatments. Control plants produced the most shoot biomass, had the longest leaves and also the greatest number of flowering culms (Table 1). Treated plants were significantly different from controls for four of the five measurements: shoot biomass, leaf length, culm length, and seedhead length. Clump location, by quadrant, had a significant effect on all measurements, but no interaction was observed between treatments and quadrant location. The size of treatment application (single plant versus 3.14 $m^2$ area) had no significant effect on any of the measurements, and no significant interaction was observed between the treatment and the size of the treated area. Precipitation from July 1979 to July 1980 averaged 28.5 cm (11.4 in.)

TABLE 1. Average values for five measures of bluebunch wheatgrass productivity measured at the end of the growing season following burning and clipping treatments ( ± standard error).

| Measure | Control | Clip Area | Clip Clump | Burn Area | Burn Clump |
|---|---|---|---|---|---|
| Biomass g dry wt. | 20.84 ± 3.97 a | 10.30 ± 0.80 b | 13.77 ± 2.33 b | 15.31 ± 1.77 ab | 14.12 ± 2.17 ab |
| Leaf length cm | 30.74 ± 1.32 a | 23.71 ± 0.65 b | 25.72 ± 1.02 b | 25.51 ± 1.25 b | 25.18 ± 0.96 b |
| Culm length cm | 30.28 ± 4.13 a | 13.54 ± 3.07 b | 21.59 ± 3.80 ab | 31.48 ± 4.86 a | 28.58 ± 4.15 a |
| Seedhead length cm | 4.37 ± 0.76 a | 2.07 ± 0.49 b | 3.13 ± 0.53 ab | 4.87 ± 0.79 a | 4.19 ± 0.62 a |
| Number of seed heads | 37.20 ± 12.86 a | 12.15 ± 4.27 a | 19.90 ± 5.97 a | 13.00 ± 4.41 a | 10.7 ± 3.42 a |

Values within rows with different letters differ significantly at $\alpha = < 0.05$.

##### Shoot Biomass

Clipping significantly reduced shoot biomass. Clipped plants produced on the average 42 percent less shoot biomass than did the controls (Table 1). No significant differences in shoot biomass were observed when the burned plants were compared to either the clipped plants or the controls.

##### Leaf Length

Clipping and burning significantly reduced leaf length. The leaves of burned and clipped plants were on the average 18 percent and 20 percent, respectively,

shorter than controls (Table 1). No significant differences in leaf length were observed when the clipped plants were compared to the burned plants.

### Flowering Culm Length

Clipping significantly reduced flowering culm length only on those plants that were treated as part of a 3.14 $m^2$ area. Culms of plants clipped as part of an area were on the average 55 percent shorter than those of both the controls and the burned plants (Table 1). Culms of plants burned as part of a 3.14 $m^2$ area were slightly, though not significantly, longer than those of controls. No significant differences were observed in culm lengths of controls, burned plants, or individually clipped plants.

### Seedhead Length

Clipping significantly reduced seedhead length only on those plants that were treated as part of a 3.14 $m^2$ area. Seedheads of plants clipped as part of an area were 53 percent shorter than the seedheads of the controls and the singly burned plants (Table 1). Seedheads of plants burned as part of an area were slightly, though not significantly, longer than those of controls. Average seedhead lengths of control plants, burned plants, and individually clipped plants were not significantly different.

### Number of Flowering Culms

The number of flowering culms produced per plant was highly variable, regardless of treatment. No significant treatment effect on the average number of flowering culms per plant was detected (Table 1).

The results of this study generally support those of other clipping studies (Sauer 1978, Blaisdell and Pechanec 1949). Clipping bluebunch wheatgrass plants during summer dormancy caused a decrease in shoot biomass and leaf length in the first growing season following treatment. Clipping did not appear to affect the number of seedheads produced per plant. The seedhead and culm lengths were reduced only on those plants that were clipped as part of an 3.14 $m^2$ area. Similarly, the results of this study are in agreement with other fire studies (Uresk *et al.* 1978, Willms *et al.* 1980). Burning bluebunch wheatgrass during dormancy had no effect on shoot biomass or reproductive performance (seedhead number, culm length and seedhead length) during the first growing season following treatment. The only effect of burning on bluebunch wheatgrass appeared to be a measurable decrease in leaf length.

Seasonal changes in stress sensitivity and competition induced by neighboring plants are thought to be the major factors responsible for the deleterious effect of grazing and clipping on bluebunch wheatgrass productivity. Grazing and most experimental clipping studies are done during the most active part of the growing season (spring) when root energy reserves (carbohydrates) are low and plants are susceptible to damage (Wilson *et al.* 1966). However, rangeland fires usually occur during the dry season (summer) after the plants have matured and dried (Wright and Klemmedson 1965). Fires also cover large areas and can reduce plant competition by killing sagebrush and some of the associated grasses and forbs. Presumably this temporary reduction in competition makes soil water and mineral nutrients more available to the surviving plants. In contrast to fire, grazing has

a selective impact on plants. Generally only the most palatable species are grazed and plant competition is unaffected. In fact, a study in southwestern Montana showed that the negative effects of clipping on bluebunch wheatgrass productivity were significantly reduced by clipping to ground level or removing neighboring plants (*Festuca idahoensis* Elmer and *Lupinus argenteus* Pursh, as well as *Agropyron spicatum*) (Mueggler 1972).

In this study we tried to control the seasonal and competitive differences between fire and clipping. Plants were treated in the fall and the surrounding vegetation within a 1 m radius was either left undisturbed or subject to the same treatment as the study plant. However, plants treated as part of an area did not respond differently from those treated as individuals. These results do not agree with those of Mueggler (1972) most likely because of seasonal differences. Based on the results of this study, it appears that differences in autumn clipping and burning on the productivity of individual plants is not due to reduced competition or treatment effects on neighboring plants.

Autumn burning and clipping both remove standing dead foliage from bunchgrasses. Standing dead foliage left in place may benefit the growth of new shoots by protecting them from wind and by shading them from direct sunlight. Shading also tends to reduce evapotranspiration stress and conserves soil water during the spring growing season (Sauer 1978). In addition, standing dead foliage has a role in water retention. It acts as a substrate for moisture condensation and retains snow longer than open areas. Standing dead foliage also is important in nutrient cycling via stem flow (Parker 1983). Therefore, it would be expected that burning and clipping would create somewhat similar microhabitats and have similar effects on bluebunch wheatgrass shoot production. However, in this study, burning had no measurable effect on shoot biomass when compared to control plants, while clipping reduced shoot production. It appears that the method of removing standing dead foliage does influence bluebunch wheatgrass shoot production during the following growing season.

Burning in contrast to clipping or grazing produces ash. Although it is doubtful that grassland fires produce enough ash to increase soil fertility (Daubenmire 1968), the ash does blacken the soil surface. The darkened suface may create higher early-season soil surface temperatures resulting in the initiation of earlier plant growth which may lead to increased production (Vogl 1974). Therefore, some of the detrimental effects of the removal of standing dead material by burning may be somewhat ameliorated by the initiation of early-season growth prompted by higher soil temperatures early in the spring growing season. As demonstrated by this study, removal of standing dead foliage by clipping a bluebunch wheatgrass plant and surrounding vegetation as well should have the most detrimental effect on productivity. The treated plant is devoid of the sheltering effects provided by its own standing dead foliage or that of the surrounding vegetation, and lacks the compensating effects of higher soil surface temperatures caused by ash deposition. Therefore it appears likely that the difference in the effects of autumn clipping and burning on the productivity of individual bluebunch wheatgrass plants is a consequence of microclimatic differences induced by treatment.

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# Mites and Lice from Mice of the Genus *Peromyscus* from Oregon[1]

## Abstract

Ectoparasitic mites (excluding chiggers) and lice were examined from 414 deer mice (*Peromyscus maniculatus*), 10 canyon mice (*P. crinitus*); and 2 piñon mice (*P. truei*) from Oregon. The more abundant mites and lice were as follows: (1) deer mice—lice, *Hoplopleura hesperomydis, Polyplax auricularis;* mites, *Androlaelaps fahrenholzi, Eubrachylaelaps debilis, Glycyphagus hypudaei, Echinonyssus utahensis;* (2) canyon mice—mites, *Eubrachylaelaps hollisteri, Ornithonyssus bacoti;* (3) piñon mice—mites, *Eubrachylaelaps circularis, Androlaelaps fahrenholzi.*

## Introduction

Allred (1957a, b, c; 1958) and Allred and Beck (1966) published papers on mites from *Peromyscus* in Utah, and Whitaker and Wilson (1974) summarized information on ectoparasitic and phoretic mites of North American mammals. Hansen (1964) was the only other person who examined a large number of mice (426) in the genus *Peromyscus* from Oregon. He examined 211 individuals of *P. maniculatus* from Steens Mountain in Harney County but found only 19 mites of six taxa; 13 of them were *A. fahrenholzi.* We present the results of a rather extensive survey of mites and lice of the genus *Peromyscus* from Oregon.

Ectoparasites were collected by searching the fur with the aid of a dissecting microscope and were preserved in 70 percent ethanol. Smaller forms were taken in low numbers. Lice and mites were cleared and stained in Nesbitt's solution containing acid fuchsin. Specimens were mounted in Hoyer's solution, and the cover slips were ringed with Euparal.

## Results

Deer Mice: *Peromyscus maniculatus* (N = 414).

Two species of anopluran lice were taken on deer mice (Table 1). *Hoplopleura*

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[1]A partial contribution of the Oregon Coast Ecological Survey, Puget Sound Museum of Natural History, University of Puget Sound, Tacoma, Washington 98416.

*hesperomydis* was more abundant than *Polyplax auricularis.* Both species of louse are to be expected on deer mice, and both were taken by Hansen (1964) along with two individuals of *Hoplopleura acanthopus,* an accidental or contaminant from its normal microtine hosts.

TABLE 1. Ectoparasitic mites (other than chiggers) and lice from 414 deer mice (*Peromyscus maniculatus*) from Oregon.

| Species | Number | | Animals infested | |
|---|---|---|---|---|
| | Total | Average | Total | % |
| LICE | | | | |
| *Hoplopleura hesperomydis* | 603 | 1.46 | 73 | 17.6 |
| *Polyplax auricularis* | 156 | 0.38 | 19 | 4.6 |
| MITES | | | | |
| *Androlaelaps fahrenholzi* | 372 | 0.90 | 91 | 22.0 |
| *Eubrachylaelaps debilis* | 140 | 0.34 | 42 | 10.1 |
| *Glycyphagus hypudaei* | 32 | 0.08 | 5 | 1.2 |
| *Euryparasitus* sp. | 28 | 0.07 | 12 | 2.9 |
| *Echinonyssus utahensis* | 26 | 0.06 | 18 | 4.3 |
| *Echinonyssus obsoletus?* | 12 | 0.03 | 5 | 1.7 |
| *Haemogamasus reidi* | 11 | 0.03 | 6 | 1.4 |
| *Radfordia subuliger* | 9 | 0.02 | 3 | 0.7 |
| *Proctolaelaps* sp. | 8 | 0.02 | 6 | 1.4 |
| *Haemogamasus ambulans* type | 6 | 0.01 | 5 | 1.2 |
| *Cyrtolaelaps* sp. | 4 | 0.01 | 4 | 1.0 |
| *Eulaelaps stabularis* | 3 | 0.007 | 3 | 0.7 |
| *Amorphacarus hengererorum* | 3 | 0.007 | 3 | 0.7 |
| *Laelaps alaskensis* | 3 | 0.007 | 3 | 0.7 |
| *Hypoaspis* sp.? | 3 | 0.007 | 3 | 0.7 |
| *Ornithonyssus bacoti* | 3 | 0.007 | 2 | 0.5 |
| *Echinonyssus isabellinus* | 2 | 0.005 | 2 | 0.5 |
| *Laelaps kochi* | 2 | 0.005 | 2 | 0.5 |
| Anoetidae | 2 | 0.005 | 2 | 0.5 |
| *Bakerdania* sp. | 2 | 0.005 | 1 | 0.2 |
| *Echinonyssus affinus* | 1 | 0.002 | 1 | 0.2 |
| *Haemogamasus occidentalis* | 1 | 0.002 | 1 | 0.2 |
| *Androlaelaps casalis* | 1 | 0.002 | 1 | 0.2 |
| *Echinonyssus "obsoletus"* variant | 1 | 0.002 | 1 | 0.2 |

The more abundant species of mites on deer mice were *Androlaelaps fahrenholzi, Eubrachylaelaps debilis, Glycyphagus hypudaei,* and *Echinonyssus utahensis. Androlaelaps fahrenholzi,* probably a complex of closely related species rather than a single species, occurs on a wide variety of hosts. *Echinonyssus obsoletus* variant is similar to *E. obsoletus,* but the spur on coxa II is acute rather than blunt. One species is listed as *Haemogamasus ambulans* type. Hansen (1964) reported *H. ambulans* from Oregon. Many of the earlier specimens reported as *H. ambulans* from Oregon, however, have been reidentified as *H. reidi* (see Redington 1970). We have not found *H. ambulans* in Oregon, although some closely related forms are present and are currently under study. Mites of the genera *Euryparasitus, Proctolaelaps, Cyrtolaelaps,* and *Bakerdania* and of the family Anoetidae were found during this study (Table 1). Although they are commonly associated with small mammals, their taxonomy and relation to their hosts need to be studied.

Canyon mice: *Peromyscus crinitus* (N = 10).

The more abundant species found on our small sample of canyon mice were mites: *Eubrachylaelaps hollisteri* and *Ornithonyssus bacoti*. These species (Table 2) are commonly taken on canyon mice (Whitaker and Wilson 1974), but the specimens of *O. bacoti* in our study differed from typical *O. bacoti* by having branched sternal setae. These specimens are being studied.

TABLE 2. Ectoparasitic mites (other than chiggers) from 10 canyon mice (*Peromyscus crinitus*) and 2 piñon mice (*P. truei*) from Oregon.

| | P. crinitus | | | | P. truei | | | |
|---|---|---|---|---|---|---|---|---|
| | Number | | Infested | | Number | | Infested | |
| Species | Total | x | No. | % | Total | x | No. | % |
| *Eubrachylaelaps hollisteri* | 21 | 2.1 | 5 | 50.0 | | | | |
| *Ornithonyssus bacoti* | 20 | 2.0 | 2 | 20.0 | | | | |
| *Eubrachylaelaps debilis* | 3 | 0.3 | 2 | 20.0 | | | | |
| *Haemogamasus occidentalis* | 2 | 0.2 | 2 | 20.0 | | | | |
| *Androlaelaps fahrenholzi* | 1 | 0.1 | 1 | 10.0 | 1 | 0.5 | 1 | 50.0 |
| *Eubrachylaelaps circularis* | | | | | 2 | 1.0 | 2 | 100.0 |

Piñon mice: *Peromyscus truei* (N = 2).

Only three mites, *Eubrachylaelaps circularis* (N = 2) and *Androlaelaps fahrenholzi* (N = 1) (Table 2), were taken from the two piñon mice examined.

Too few data are available to comment concerning the ectoparasites found on *P. crinitus* or *P. truei*. A total of 24 taxa of mites (some identified to genus or family only) were identified from the 414 deer mice examined. This, of course, much exceeds the listing of six taxa by Hansen (1964).

Allred and Beck (1966) listed 36 taxa from *P. maniculatus* (N = 3077) in Utah; Mumford and Whitaker (1982) listed 9 taxa from this species from Indiana (N = 454), and Whitaker and Lukoschus (1982) listed 26 taxa from Pennsylvania. The mite community on *P. maniculatus* may have been somewhat reduced because in Indiana only one subspecies of that host exists and it inhabits a rather uniform habitat (open and cultivated fields). In addition, the differing results from Oregon, Utah, Indiana, and Pennsylvania likely result in part from differing degrees of thoroughness in making the examinations, as well as from geographic differences in parasite communities.

The following species of mites have not previously been reported from deer mice: *Echinonyssus obsoletus, E. affinus, Amorphacarus hengererorum, Laelaps alaskensis,* and *Haemogamasus occidentalis*. A new host record for canyon mice was *H. occidentalis*.

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University, Corvallis, Oregon) read and improved this paper. V. Bissell (USDI Bureau of Land Management, Forestry Sciences Laboratory, Corvallis, Oregon) typed the various drafts of the manuscript. We thank them for their help.

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## Association News

### 1985 Annual Meeting, New Officers and Trustees

The 58th annual meeting of the Northwest Scientific Association was held May 22-25 on the campus of the University of British Columbia. The meeting included a symposium on Renewable Resource Management in the Pacific Northwest: The Influence of Economic, Political and Social Trends. In addition to the symposium there were approximately 85 contributed papers in the following sections: Aquatic Sciences, Botany, Chemistry, Physics, Mathematics, Statistics, Environmental Science, Engineering, Evolutionary Biology, Forest Science, Applied Forest Sciences, Geology, Geography, Social Science, Zoology, Microbiology and Computer Science.

Research grants totaling $1950 were awarded to Mark Tiritilli, Washington State University; Steven R. Antell, Washington State University; Katherine Volz, Washington State University; Jeffrey L. Strachan, University of Montana; Loren H. Rieseberg, Washington State University; Jennifer A. Clark-Mace, Washington State University; Corey Y. Fullmer, Eastern Washington University.

New officers for the association are President Raymond Soltero, Eastern Washington University; and President-elect Donald Hanley, Washington State University. New trustees are Robert Antibus, University of Montana; Larry Larson, Oregon State University; Bill Rickard, Battelle Northwest Laboratories; Harry Smith, University of British Columbia; and Steve Tesch, Oregon State University.

### 1986 Annual Meeting

The meeting dates for the 59th annual meeting of the association at Eastern Washington University are March 26-29, 1986.

There will be symposia on Monitoring Aquatic and Riparian Ecosystems in Natural Areas, Northwest Power Planning Council's Columbia Basin Fish and Wildlife Program, Quaternary History of the Columbia Plateau, Columbia Plateau Anthropology, and Chemical Pollutants in the Environment from Industrial Sources in the Pacific Northwest.

Contributed papers are invited from forest science, aquatic science, biochemistry/biotechnology, botany, chemistry/physics, environmental science/engineering, forest science, geology/geography, mathematics/statistics, microbiology, science education, social science, soils, and zoology.

Banquet speaker Bill A. Williams, research scientist for the Environmental Protection Agency and payload specialist in the Civilian Astronaut Programs, will present a view of NASA's space shuttle program.

For additional information contact the University Conference Center, Eastern Washington University, Cheney, Washington 99004.

### Research Grants/Research Funds

Applications for research grants for 1986 should be mailed to the secretary of the Northwest Scientific Association no later than 5 January 1986. Successful applicants will be notified by April 1986. For more information or application forms write to: Robert L. Carr, Secretary, NWSA, Department of Biology, Eastern Washington University, Cheney, Washington 99004.

All members are encouraged to make voluntary contributions to the NWSA Research Fund at any time. These funds assist the NWSA in providing annual research grants. Contact Steve Brunsfeld, Treasurer.

#### Call for Nominations for Officers, Trustees, Honorary Life Members, and Outstanding Scientist.

Nominations for Outstanding Northwest Scientist or for Honorary Life Membership should be sent by 5 January 1986 to Robert E. Stockhouse II, Chairman Division of Natural Science, Pacific University, Forest Grove, Oregon 97116.

Nominations for President-elect, Editor, Treasurer, and for five trustee positions should be sent by 5 January 1986 to Lee Eddleman, Oregon State University, Corvallis, Oregon 97331.

#### Symposia Proceedings

Proceedings of three symposia held in conjunction with the 1984 annual meeting in Missoula are now available (free) from the Intermountain Research Station, USDA Forest Service, 324 25th St., Ogden, UT 84401. The three titles are Research Natural Areas: Baseline Monitoring and Management; Recreation Choice Behavior; and Fire's Effects on Wildlife Habitat.

#### New Northwest Scientific Association Constitution

The following revised constitution will be voted upon at the annual meeting at Eastern Washington State University, March 26-29, 1986. Since revisions were quite extensive, no attempt was made to give a detailed comparison with the present constitution. Please direct comments or questions to the association secretary.

**Article I.** Name

This society shall be known as the Northwest Scientific Association.

**Article II.** Purpose

The purpose of the Association shall be the promotion of scientific research and the dissemination of scientific knowledge.

**Article III.** Membership

Membership in this Association shall consist of the following categories:

(1) Member: Any individual interested in the purpose of the Association may become an individual member upon payment of annual dues. Members have all privileges including voting, holding office, and receiving *Northwest Science.*

(2) Student Member: Any high school or college student may become a member of the Association upon the payment of annual student membership dues. Student members shall receive *Northwest Science* and will have all privileges of membership except voting and holding office.

(3) Institutional Member: There shall be two categories of institutional memberships, upon payment of institutional membership annual dues:

a. Institutional Member (large): Available to all universities, colleges, community colleges, and similar educational institutions with enrollment of 3,000 or more students.

b. Institutional Member (small): Available to all universities, colleges, community colleges, and similar educational institutions with enrollments of less than 3,000 students and to professional, business, research organizations, and public agencies.

Institutional membership carries no voting nor office-holding privileges, but institutions shall receive *Northwest Science.*

(4) Honorary Life Member or Outstanding Scientist: The Awards and Honors Committee shall solicit nominations for Honorary Life member from the membership of the Northwest Scientific Association. The Awards and Honors Committee will submit the nomination(s) to the Governing Board for majority approval. Nominations will then be submitted to the general membership at the annual meeting for approval. Honorary life membership carries all privileges of membership.

(5) Sustaining Members: Two classes of sustaining memberships shall exist.

a. Individual Sustaining Member: This class of membership is available to any individual upon payment of individual sustaining membership annual dues. Individual sustaining members have all privileges of members, including voting, office holding and receiving *Northwest Science.*

b. Organizational Sustaining Member: Any institutional member may select the alternative of becoming a sustaining member upon payment of the necessary organizational sustaining membership annual dues. The organization will receive *Northwest Science.*

**Article IV.** Officers

The officers shall consist of a President, President Elect, Secretary, Treasurer, and immediate past President. This group will be called the Executive Committee.

All officers shall be nominated by the nominating committee or by members from the floor at the annual meeting.

Election shall be by vote of members present at the annual business meeting.

To enhance continuity, all officers shall normally be elected from the membership of the present or recent past Governing Boards.

Vacancy of the office of President is filled by advancement of the President Elect. Replacements for vacancies in other offices shall be appointed by the President.

The term of the President and President Elect shall be one year.

The term of the Secretary or Treasurer shall be three years.

**Article V.** Editor

The Editor shall be appointed by the Executive Committee.

The term of the Editor shall be three years.

**Article VI.** Governing Board

1. The Governing Board of the Association shall consist of twenty-two members. The officers of the association, the editor of *Northwest Science,* the Program Chairman, and the immediate past President shall serve ex-officio (with vote). The remaining fifteen members (Trustees) shall serve 3 year terms. Five trustees shall be elected each year to replace those whose terms expire. Trustees shall be nominated by the nominating committee and by members from the floor at the annual meeting. Election shall be by a vote of members present at the annual business meeting.

Vacancies, including those arising from the election of a Trustee to one of the ex-officio offices, shall be filled by the president as they occur. The person so appointed shall hold office until the next regular election at which time a member shall be elected to fill the remainder of the unexpired term.

2. The Governing Board shall represent the Association, and carry on its affairs during the interim between annual meetings. The responsibilities and authority of the Trustees shall include: Making plans and programs for meetings, supervising the publication of a journal and other publications, and serving as custodian of all property and funds of the Association. The trustees are authorized to use the funds under their jurisdiction for awards and grants-in-aid.

3. The expenditure or transfer of funds from trust funds (as distinguished from the treasurer's checking-savings account for routine operation) of the Association must be approved by the Governing Board and disbursed on vouchers signed by both the president and treasurer.

4. The bonding of the officers shall be as decided by the Trustees. The expense of the bond will be paid from funds of the Association. The funds under jurisdiction of both the treasurer and the Trustees shall be audited each year by an Auditing Committee appointed for that purpose and a report made at the annual meeting by this committee.

5. The Governing Board of the Association shall have the authority and responsibility to prepare a set of bylaws and to amend them as needed.

**Article VII.** Committees

1. Executive Committee. The Executive Committee, composed of the President, President Elect, Secretary, Treasurer, and Past-President, shall carry on the business of the Association that does not

require a vote of the trustees. The President will assume the responsibility of initiating action by calling a meeting or corresponding through the mail.

2. Nominating Committee. This Committee shall consist of three members, each to serve a three year term. The President of the Association shall appoint one member each year. The committee member in his/her third year shall serve as chairperson. This committee shall nominate officers and trustees of the Association, the names of which are to be presented at the annual business meeting.

3. Research Grants Committee. This Committee shall consist of three members, each to serve a three year term. The President of the Association shall appoint one member each year. The committee member in his/her third year shall serve as chairperson. This Committee shall consider requests for grants from the Research Fund and recommend to the Governing Board candidates for grants.

4. Awards and Honors Committee. This Committee shall consist of three members, each to serve a three year term. The President of the Association shall appoint one member each year. The committee member in his/her third year shall serve as chairperson. This Committee may recommend candidates for special honors and awards to the Governing Board.

5. *Ad Hoc* Committees. The President of the Association shall appoint *ad hoc* committees such as the program, auditing, resolutions, environmental affairs, and other committees for special purposes and functions at any time during the year to further the interests of the Association.

**Article VIII.** Outstanding Scientist

The Awards and Honors Committee shall make recommendations to the Governing Board for the award of Outstanding Scientist.

**Article IX.** Meetings

The annual meeting shall be held at such time and place as the Governing Board shall decide, and special meetings may be called at the request of three members of the Governing Board. The President may call meetings of the Governing Board between the annual meetings.

**Article X.** Amendments

Amendments to this constitution may be made at any annual meeting by a vote of three-fourths of the members present and voting, providing notice of such amendment has been reported in the official program and has been published in an issue of *Northwest Science* so as to reach the membership at least thirty days before that annual meeting. Proposed amendments presented to the association must first be approved by the Governing Board.

**Article XI.** Dissolution

Upon the dissolution of the Northwest Scientific Association, the Governing Board shall, after paying or making provision for the payment of all of the liabilities of the Association, dispose of all of the assets of the Association exclusively for the purposes of the Association in such manner, or to such organizations or organizations organized and operated exclusively for educational or scientific purposes as the Governing Board shall determine and which shall at the time qualify as an exempt organization or organizations under proper provision of the United States Internal Revenue Law.

**Honorary Life Members**

William H. Baker
Ewart M. Baldwin
Irven O. Buss
L. C. Cady
Charles D. Campbell
Julian L. Culbertson
Rexford Daubenmire
Glenn Deitschman
R. A. Diettert
Bruce V. Ettling
William K. Ferrell
C. Clement French
Stanley P. Gessel
N. S. Golding
Phil Haddock
H. P. Hansen
Adolph Hecht
Kenneth Holmes
G. Brooks King
Rufus W. Kiser
Lewis and Clark High School Library (In memory of Thomas Large and J. G. McCracken)
Willis B. Merriam
Joseph W. Mills
Milton M. Mosher
Richard J. Naskali
Frank D. Nicol
Frances J. Schadegg
C. Gardner Shaw
Leona M. Sundquist
Robert F. Tarrant
Richard B. Walker
D. J. Wort

**1985 Sustaining Institutional Members**

Battelle Northwest, Richland Washington
EG&G Idaho, Inc., Idaho Falls, Idaho
MacMillan Bloedel, Ltd., Nanaimo, British Columbia, Canada
Potlatch Corporation, Lewiston, Idaho
The Washington Water Power Company, Spokane, Washington
Weyerhaeuser Company, Centralia, Washington

**1985 Institutional Members**

British Columbia Institute of Technology, Burnaby, British Columbia, Canada
Central Oregon Community College, Bend, Oregon
Central Washington University, Ellensburg, Washington
Centralia College, Centralia, Washington
College of Idaho, Caldwell, Idaho
Eastern Montana College, Billings, Montana
Eastern Oregon State College, LaGrande, Oregon
Eastern Washington University, Cheney, Washington
Edmonds Community College, Lynnwood, Washington
The Evergreen State College, Olympia, Washington
George Fox College, Newberg, Oregon
Grays Harbor Colelge, Aberdeen, Washington
Green River Community College, Auburn, Washington
Highline Community College, Midway, Washington
Idaho State University, Pocatello, Idaho
Lewis-Clark State College, Lewiston, Idaho
Lewis and Clark College, Portland, Oregon
Linfield College, McMinnville, Oregon
Montana College of Mineral Science and Technology, Butte, Montana
Mt. Hood Community College, Gresham, Oregon
Oregon Institute of Technology, Klamath Falls, Oregon
Oregon State University, Corvallis, Oregon
Pacific Lutheran University, Tacoma, Washington
Pacific University, Forest Grove, Oregon
Peninsula College, Port Angeles, Washington
Portland State University, Portland, Oregon
Seattle Central Community College, Seattle, Washington
Shoreline Community College, Seattle, Washington
Simon Fraser University, Burnaby, British Columbia, Canada
Skagit Valley College, Mount Vernon, Washington
Southern Oregon State College, Ashland, Oregon
Southwestern Oregon Community College, Coos Bay, Oregon
Spokane Falls Community College, Spokane, Washington
University of Alaska, Fairbanks, Alaska
University of Idaho, Moscow, Idaho
University of Montana, Missoula, Montana
University of Puget Sound, Tacoma, Washington
University of Victoria, British Columbia, Canada
University of Washington, Seattle, Washington
Walla Walla College, College Place, Washington
Washington State University, Pullman, Washington
Western Washington University, Bellingham, Washington
Whitman College, Walla Walla, Washington
Yakima Valley College, Yakima, Washington

**1985 Sustaining Individual Members**

Stephen F. Arno, Florence, Montana
Donald J. Brown, Richland, Washington
Randall E. Brown, Pasco, Washington
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# Northwest Science

## General Information

Publication in *Northwest Science* is open to scientists in the basic, applied, and social sciences who are engaged in original or fundamental research. *Northwest Science* does not publish notes, letters, or bibliographic papers. All submissions are reviewed by at least two referees and one associate editor. While submissions from outside the Pacific Northwest are welcome, at least one author of all papers considered for publication must be a member of the Northwest Scientific Association.

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**Page Charges**—Page charges are currently $60 per printed page. Petition for partial payment or waiver of these charges should be directed to the Editor upon the manuscript's being accepted for publication.

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An abstract, double-spaced and not exceeding five percent of the paper, should precede every article. The abstract should recapitulate the major points of the paper and should be suitable for use by abstracting services.

Literature citations should have the author's name and year of publication in the text; e.g. (Jones 1978). Citations should be double-spaced and listed in alphabetical order at the end of the article.

Present all data in international (SI) units. English equivalents may be added parenthetically. Use the 24-hour clock (0600 and 2300) and continental dating (17 November 1982).

Equations should be presented camera-ready. Symbols should be large enough to be legible after a 1/3 to 1/2 reduction in size, but not overly large.

Tables should be typewritten (double-spaced) separately from the text. Original art work or glossy prints of photographs must be submitted for reproduction. Art work and lettering should be large enough (but not overly large) to provide clarity after a 50 percent reduction in size for printing. The author's name and figure number should be penciled on the back of each illustration. Provide a scale for distance on map illustrations. Legends for illustrations should be typed (double-spaced) as a section of the manuscript; do not use a separate page for each legend.

Length of manuscripts is limited to 15 pages of printed copy. Two typed pages are approximately equal to one journal page.

**Authors of Biological Papers**—On first mention, a species should be designated by common name followed by systematic binomial. For abbreviations and forms of titles for serial publications, follow the *BIOSIS List of Serials*. Consult with the *Council of Biology Editors (CBE) Style Manual*, 4th ed., for general information on manuscript preparation.

**Correspondence**—Correspondence will be between senior author and the Editor.

**Editing**—In addition to being reviewed by two referees and an associate editor, manuscripts will be edited for grammatical correctness and clarity.

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